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THE PURPOSE OF THE INVESTIGATION WAS TO APPRAISE THE GROUND WATER RESOURCES OF THE BASIN. THEREFORE, THE CHARACTER, THICKNESS, AND EXTENT OF THE WATER-BEARING FORMATIONS WERE STUDIED; AND THE ORIGIN, QUANTITY, MOVEMENT, AVAILABILITY, AND USE OF THE GROUND WATER WERE DETERMINED. ALSO, THE CHEMICAL COMPOSITION OF THE WATER WAS DETERMINED. RELATIONS OF THE CHEMICAL COMPOSITION TO THE GEOLOGY AND HYDROLOGY OF THE AREA WERE STUDIED, AND THE SUITABILITY OF THE WATER FOR USE WAS EVALUATED. SPECIAL CONSIDERATION WAS GIVEN TO AREAS IN WHICH LARGE SCALE PUMPING IS INCREASING OR IN WHICH PRESENT OR FUTURE GROUND WATER WITHDRAWALS MAY EXCEED THE SAFE PERENNIAL YIELD OF THE AQUIFERS.

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Ground-Water Resources of the South Platte River Basin in Western Adams and Southwestern Weld Counties Colorado

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1658

Prepared as part of the program of the Department of the Interior for development of the Missouri River basin

Ground-Water Resources of the South Platte River Basin in Western Adams and Southwestern Weld Counties Colorado

By REX O. SMITH, PAUL A. SCHNEIDER, Jr., and LESTER R. PETRI

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By REX O. SMITH, PAUL A. SCHNEIDER, JR., and LESTER R. PETRI

ABSTRACT

The area described in this report consists of about 970 square miles in western Adams and southwestern Weld Counties in northeastern Colorado. It includes that part of the South Platte River valley between Denver and Kuner, Colo., all of Beebe Draw, and the lower part of the valley of Box Elder Creek. The stream-valley lowlands are separated by rolling uplands. The climate is semiarid, the normal annual precipitation being about 13 inches; thus, irrigation is essential for stable agricultural development. The area contains about 220,000 acres of irrigated land in the stream valleys. Most of the remaining 400,000 acres of land is used for dry farming or grazing because it lacks irrigation water. Most of the lowlands were brought under irrigation with surface water during the early 1900's, and now nearly all the surface water in the area is appropriated for irrigation within and downstream from the area. Because the natural flow of the streams is sometimes less than the demand for water, ground water is used to supplement the surface-water supply. Wells, drilled chiefly since 1930, supply the supplemental water and in some places are the sole supply for irrigation use.

Rocks exposed in the area are of sedimentary origin and range in age from Late Cretaceous to Recent. Those that are consolidated, called "bedrock" in this report, consist of the Fox Hills sandstone and the Laramie and Arapahoe formations, all of Late Cretaceous age, and the Denver formation and Dawson arkose of Late Cretaceous and Tertiary age. The surface of the bedrock was shaped by ancestral streams, the valleys of which are reflected by the present surface topography. Dune sand, slope wash, and thin upland deposits of Quaternary age mantle the bedrock in the divide areas, and stream deposits ranging in thickness from 0 to about 125 feet partly fill the ancestral valleys. The valley-fill deposits consist of beds and lenses of clay, silt, sand, gravel, cobbles, and boulders.

Abundant supplies of ground water for irrigation, municipal, and industrial use are obtained in the principal stream valleys from wells tapping valley-fill deposits beneath the flood plain and bordering terraces. Many domestic and stock wells obtain water from the unconsolidated deposits both on the uplands and in the valleys. The ground water in the valley-fill deposits generally is unconfined but in a few places is under slight artesian pressure. The bedrock formations yield small to moderate supplies of water to municipal, industrial, domestic, and stock wells, but the yields are not sufficient for irrigation.

Ground water in the South Platte River valley moves downstream and toward the river and is discharged into the river. The direction of ground-water move-

ment in Beebe Draw and Box Elder Creek valley is nearly parallel to the streams. Beebe Seep, the stream in Beebe Draw, gains water from the ground-water reservoir in some reaches and loses water in others, but Box Elder Creek loses water to the ground-water reservoir throughout its course, especially during floods. The shape and slope of the water table are affected chiefly by the permeability of the valley-fill deposits, the location and altitude of the areas of recharge and discharge, and the configuration of the underlying bedrock floor. The depth to water in the South Platte River valley ranges from less than 1 foot beneath the flood plain to as much as 80 feet beneath the terraces. In Beebe Draw the depth to water ranges from less than 1 foot to about 60 feet and in Box Elder Creek valley from about 5 feet to about 40 feet. During the period of record the annual fluctuation of water levels in wells in the area has ranged from 2 to 13 feet. Precipitation within the area and infiltrating water from irrigated tracts, reservoirs, canals, and streams are the principal sources of recharge to the ground-water reservoir; some recharge results from underflow from outside the area. Ground water is discharged by evapotranspiration, seepage into streams, springs, underflow out of the area, and by pumping from wells. Evapotranspiration is especially great in areas where the water table extends to the land surface or to the root zone of the vegetation.

The number of large-capacity wells tapping the valley-fill deposits increased from about 700 in 1940 to about 1,700 by 1958. The yields that were measured by the U.S. Geological Survey ranged from 45 to 2,040 gpm (gallons per minute) and averaged about 700 gpm. Measured drawdowns were within a range of 1 to 50 feet, and specific capacities ranged from 5 to about 300 gpm per ft of drawdown. Aquifer tests indicate that the coefficient of transmissibility of the valley-fill deposits ranges from 35,000 to 500,000 gpd per ft (gallons per day per foot). The average coefficient of storage was determined to be about 0.20. The quantity of recoverable ground water in storage in the report area in November 1957 (the approximate quantity that could be withdrawn by pumping under ideal conditions) was estimated to be about 2 million acre-ft. It is estimated that about 250,000 acre-ft of ground water in 1956, a dry year, and about 100,000 acre-ft in 1957, a wet year, were pumped from the large-capacity wells in the area. Probably the average, 175,000 acre-ft, would be pumped during a normal year under present conditions to irrigate 100,000 acres.

The chemical composition of the ground water was determined by analyzing water samples from about 200 wells that tap the valley-fill deposits and from 12 wells that tap the bedrock.

In most of the report area the water in the valley-fill deposits has a specific conductance between 1,000 and 1,800 micromhos per cm and is of either the calcium bicarbonate or the calcium sulfate type. In some places, however, the water has a specific conductance of about 2,250 micromhos per cm and is of the sodium sulfate type. Water of the calcium chloride type having a specific conductance of more than 4,000 micromhos per cm indicates severe contamination of the ground water in parts of T. 2 S., R. 67 W. The water in most of the report area is of suitable quality for irrigation except that it has a high or very high salinity hazard; in some places the leaching requirements of the water are so high that special farming methods for salinity control are needed to prevent accumulation of large amounts of salts in the root zone of the soil. Because the water is very hard, it is of poor quality for public supply and domestic use.

The specific conductance and the chemical type of the water in the bedrock differ widely from one stratigraphic unit to another and also within some of the units. Water from most of the units is of the sodium bicarbonate type, is soft, and has a relatively high concentration of fluoride. Water from bedrock

aquifers is of poor quality for irrigation and is poor to good for public supply and domestic use.

Although the available data indicate that the ground-water resources in some parts of the report area are capable of additional development, it is clear also that the data are insufficient to determine the quantity of additional ground water that can be withdrawn without exceeding the safe perennial yield or to determine the effects of such withdrawal upon surface-water use. Therefore, additional development should be preceded and accompanied by further and more comprehensive water-resource studies. Such studies should include an evaluation of the sources and amounts of ground-water recharge and discharge, a quantitative analysis of the relation between surface water and ground water, and an evaluation of the effects of ground-water withdrawals on the total water supply. Measurement of water levels, chemical analysis of water samples from a network of observation wells, compilation of complete records of additional large-capacity wells, and annual computation or estimation of the total volume of withdrawals from the large-capacity wells should be continued throughout the report area.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The extensive use of ground water for irrigation, municipal, and industrial supplies, intensified local development, and the continuing search for supplemental water have resulted in the need for a thorough appraisal of the ground-water resources of the South Platte River basin between Denver and Kuner, Colo. Irrigation, the principal use of water in the area, depends on diversions from streams and storage reservoirs and, to a rapidly increasing degree, on water pumped from wells. Expanding municipalities and industries also are turning to ground water for adequate water supplies. The amount of ground water available for use in the area is governed by the amount of water in storage in the ground-water reservoir, the capacity of the reservoir to yield water to wells, and the rate of recharge to the reservoir. In some parts of the area, successful utilization of ground water may be restricted by the adverse chemical characteristics of the water. This report indicates existing and potential problems; therefore, it will aid in planning the future development of the area.

The purpose of the investigation was to appraise the ground-water resources of the basin. Therefore, the character, thickness, and extent of the water-bearing formations were studied, and the origin, quantity, movement, availability, and use of the ground water were determined. Also, the chemical composition of the water was determined; relations of the chemical composition to the geology and hydrology of the area were studied, and the suitability of the water for use was evaluated. Special consideration was given to areas in which large-scale pumping is increasing or in which present or future

ground-water withdrawals may exceed the safe perennial yield of the aquifers.

The investigation is one of many being made by the U.S. Geological Survey as part of the program of the Department of the Interior for the conservation, development, and use of the water resources of the Missouri River basin; it was made at the request of the U.S. Bureau of Reclamation.

LOCATION AND EXTENT OF THE AREA

The area described in this report consists of about 970 square miles in western Adams and southwestern Weld Counties, Colo. It includes the South Platte River valley between Denver and Kuner, Colo., all of Beebe Draw, and the lower part of the valley of Box Elder Creek. The maximum north-south length of the area is 48 miles, and the width ranges from 12 to 26 miles. The southern half of T. 6 N., Rs. 64 and 65 W. is not discussed in this report; it is included on the maps only to show the location of aquifer-test sites and test holes that were pertinent to the study.

PREVIOUS INVESTIGATIONS

The geology of the report area is mentioned briefly by Hague and Emmons (1877), King (1878), White (1878), and Eldridge (1889) in reports that covered large areas of the Western United States. A detailed report by Emmons, Cross, and Eldridge (1896) on the economic geology of the Denver basin contains useful data on early ground-water development. Darton (1905) made the first general ground-water investigation of the central Great Plains, which includes the South Platte River valley. Henderson (1920) described the geology of the consolidated rock formations in part of the area, with emphasis on paleontology. A report by Mather, Gilluly, and Lusk (1928) on the oil and gas resources of the area contains many useful geologic data. The Fox Hills sandstone is discussed in a report by Lovering and others (1932), and reports on petroleum investigations in the area were prepared by Rankin (1933), Dane and Pierce (1936), and Van Tuyl and others (1938). Bryan and Ray (1940) described the terrace deposits in the South Platte River valley and discussed the Pleistocene and Recent history of the region. Two reports by Code (1943, 1958) contain many useful data on water-table fluctuations and the use of ground water for irrigation in the South Platte River basin. Lovering and Goddard (1950) described the geology and ore deposits of the Rocky Mountain Front Range in a report that contains a generalized geologic map of the area. A report by Hunt (1954) describes the Pleistocene and Recent mantle-rock deposits in the Denver area. Bjorklund and Brown (1957) made an

extensive study of the geology and ground-water resources of the South Platte River basin between Hardin, Colo., and Paxton, Nebr., which adjoins this report area on the east; the ground-water problems and some of the geologic units they described are similar to those studied during this investigation.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork on which this report is based was started in August 1955 and was under the supervision of T. G. McLaughlin, district geologist of the Ground Water Branch of the U.S. Geological Survey for Colorado. The quality-of-water phase of the work was begun under the supervision of P. C. Benedict, regional engineer in charge of quality-of-water studies in the Missouri River basin and was completed under the supervision of D. M. Culbertson, district engineer of the Quality of Water Branch. The fieldwork for the investigation was completed in March 1958.

During the investigation, records of 1,706 wells in the area were obtained, including 1,677 wells of large capacity that were constructed for irrigation, public supply, or industry, and 29 wells of small capacity that were constructed for domestic, stock, or other uses. At the time of the investigation, 139 of the wells inventoried were unused. The inventory included nearly all the wells of large capacity; the wells of small capacity were inventoried only in areas where additional information was needed. Well owners, tenants living on property where wells are situated, and drillers were interviewed regarding wells. Information regarding total depth, depth to water, geologic source of water, rate of discharge, amount of water-level drawdown, hours pumped, and acreage irrigated was collected for most of the irrigation wells. An electric tape was used to measure the drawdown, and a steel tape was used to measure the depth to water and the total depth of the wells. Measurements of discharge were made principally with Hoff current meters, Parshall flumes, and pitot tubes. Well records previously obtained by Mr. W. E. Code, irigation engineer, Colorado State University, were studied and the wells were revisited. Aquifer tests were made on 36 irrigation wells and on 5 municipal and industrial wells to determine the hydrologic properties of the water-bearing materials.

A network of 32 observation wells was established early in the investigation for monthly measurement of the water level to determine the seasonal fluctuations of the water table. Water levels were measured twice yearly by Mr. Code in additional observation wells throughout the area, and long-term records for 12 of his wells were selected for inclusion in this report as hydrographs. During the first 2 weeks of November 1957 the depth to water was measured in

350 wells throughout the area, including the observation wells, to provide data for maps showing the depth to water, water-table contours, and the thickness of the saturated valley-fill deposits. The altitude above mean sea level of the measuring points of the wells and test holes was determined by spirit leveling or from published topographic maps.

A reconnaissance investigation was made of the geology of the area with emphasis on the unconsolidated water-bearing rock materials. Information on the geology was supplemented by drilling test holes; the drilling was supervised and the holes were logged by geologists of the U.S. Geological Survey. Some of the holes were drilled by contractors and some by the staff of the Geological Survey Hydrologic Laboratory in Denver. Drillers' logs of wells were collected from the Colorado Water Conservation Board, from drillers, from well owners, and from other sources, and many of them were selected for publication. In addition, logs of seismograph shotholes were collected from oil companies. The logs of the test holes and wells and of selected seismograph shotholes were used in the construction of a bedrock-contour map, a geologic map, and 10 geologic cross sections.

The records and logs of wells appear separately in Basic-Data Report No. 9 (Schneider, 1962).

The geologic and hydrologic field data were recorded on aerial photographs and on topographs quadrangle maps, then transferred to overlays made of a dimensionally stable transparent material. The overlays were registered with a base map, which was prepared on the same stable-base material from U.S. Geological Survey topographic maps. Wells were located within each section by inspection of enlarged aerial photographs and by pacing; the locations are believed to be accurate within about 200 feet.

Samples of water were collected from 204 representative wells and springs and from 5 streams. Chemical analyses of the samples were made in the laboratories of the U.S. Geological Survey at Lincoln, Nebr., and Denver, Colo.

The Colorado Water Conservation Board permitted access to its files on wells. Well owners in the area cooperated to the fullest extent in supplying information about their wells and permitting access for measurements. Information regarding public-supply wells was given by city and town officials of Thornton, Brighton, Fort Lupton, Platteville, LaSalle, Greeley, Kersey, Keenesburg, and Hudson. Mr. W. E. Code of the Colorado State University made available many data from his previous ground-water investigations within the area. Electric-power data for irrigation pumps was furnished by

the Public Service Co. of Colorado at Brighton and Denver, the Colorado Central Power Co. at Fort Lupton, the Home Light and Power Co. at Greeley, and the Rural Electric Association at Brighton, Fort Collins, and Fort Morgan. Many well drillers and drilling companies contributed logs of wells and test holes and supplied useful information regarding depths to water and bedrock. The following oil companies made available their logs of shotholes drilled during seismic surveys: the Texas Co., the Continental Oil Co., and the Shell Oil Co. Messrs. C. E. Davies and R. O. Kane, of the U.S. Department of Agriculture, permitted use of large-scale aerial photographs of the area. Officials of the Rocky Mountain Arsenal at Derby, Colo., permitted access to wells on Arsenal property and provided logs of test holes and data on an aquifer test. Data on other aquifer tests were furnished by the Northwest Utilities Co., Thornton; the North Washington Water and Sanitation District, Welby; and Ebasco Services, Inc., Denver. The U.S. Air Force flew aerial photography missions and provided low-oblique aerial photographs of parts of the report area. The assistance of all these individuals and organizations is gratefully acknowledged.

Many individuals in the Denver office of the Ground Water Branch made substantial contributions to the report. The principal authors were assisted in basic analyses, compilation of data, and preparation of the principal maps and the geologic cross sections by E. D. Jenkins, W. W. Wilson, J. H. Irwin, W. G. Weist, Jr., L. A. Hershey, P. T. Voegeli, Sr., D. L. Coffin, H. E. McGovern, and V. M. Burtis. The manuscript of this report was reviewed critically by S. W. Lohman, T. G. McLaughlin, G. H. Chase, and R. C. Scott. Lack of space prohibits listing individually all the other personnel of the Ground Water and Quality of Water Branches who provided assistance, both in the field and in the office, but their contribution is no less appreciated.

WELL-NUMBERING SYSTEM

Well numbers in this report are based on the Bureau of Land Management's system of land subdivision. The well number shows the location of the well by township, range, section, and position within the section. Figure 1 is a graphical illustration of this method of well numbering. The capital letter indicates the quadrant of the meridian and base-line system in which the well is located; the quadrants are lettered beginning in the northeast quadrant with (A) and proceeding counterclockwise. All wells in this area lie in the northwest (B) or southwest (C) quadrant of the sixth principal meridian and 40th parallel base-line system. The first segment of the well number indicates the townships, the second the range, and the third

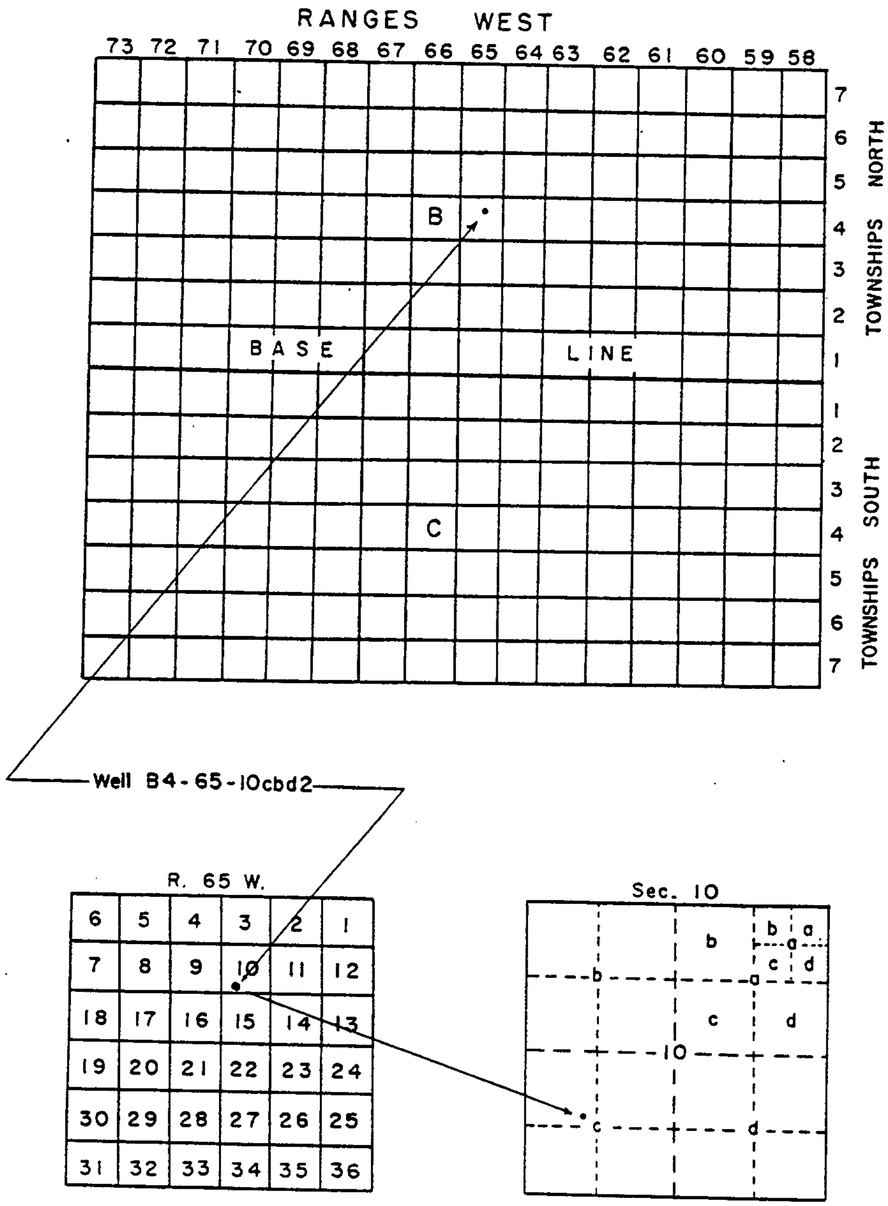

FIGURE 1.—Sketch showing well-numbering system.

the section in which the well is located. The lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section. Quarter sections are lettered a, b, c, and d in counterclockwise order, from the northeast quarter of each section. Within the quarter sections the

40-acre and the 10-acre tracts are lettered in the same manner. If more than one well is located in a 10-acre tract, consecutive numbers beginning with 1 are added to the lowercase letters. For example, well B4–65–10cbd2 is the second well that was visited in SE¼NW¼-SW¼ sec. 10, T. 4 N., R. 65 W.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The part of the South Platte River basin that is described in this report is in the Colorado Piedmont section of the Great Plains physiographic province. It consists of stream-valley lowlands separated by gently rolling uplands. The maximum local topographic relief in the area is about 500 feet; the altitude above mean sea level ranges from about 5,550 feet at the southern boundary of the report area to about 4,550 feet at the northeastern boundary.

The overall surface drainage in the region is toward the northeast, and all of the project area is drained by the South Platte River and its tributaries. The South Platte River rises in the Rocky Mountains southwest of Denver, enters the Piedmont section about 25 miles south-southwest of Denver, and then flows in a general north-northeastward direction to the vicinity of Greeley, where it swings toward the east.

The major perennial tributaries of the South Platte River in the project area are Clear Creek, Big and Little Dry Creeks, St. Vrain Creek, the Big Thompson River, the Cache la Poudre River, Lone Tree Creek, and Crow Creek. Several intermittent streams also enter the river. Of these, Beebe Seep (in Beebe Draw) and Box Elder Creek are the major ones and drain most of the report area between the South Platte River and the east boundary of the report area.

The flood plain of the South Platte River averages about a mile in width and has an irregular surface that consists of swamps, oxbow lakes, abandoned meander scars, and low, indistinct terraces. In most places the flood plain is largely on the west and north sides of the river and is bordered by two distinct terraces, which slope gently toward the river. The terraces are separated from the flood plain of the river and from each other by well-defined escarpments (fig. 2), and both extend part way up the major western tributary valleys. Bryan and Ray (1940, p. 25–26) named the lower of these the Kuner terrace and the higher the Kersey terrace. The Kuner terrace is 10–15 feet above the flood plain of the river and is discontinuous along both sides of the valley. The Kersey terrace, a much broader, flat surface, is 20–40 feet above the flood plain and is one of the most prominent features in the valley (fig. 3).

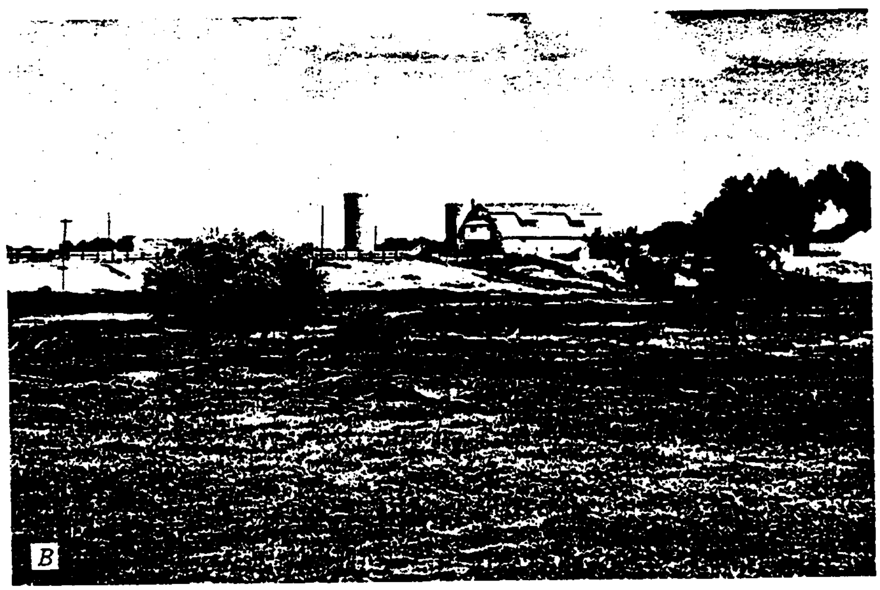

FIGURE 2.—West face of the Kersey terrace in (*A*) NE¼SE¼NE¼ sec. 30, T. 2 S., R. 67 W. and in (*B*) NW¼NE¼SE¼ sec. 7, T. 1 N., R. 66 W. In the foreground is the flood plain of the South Platte River. Photographs by G. H. Chase.

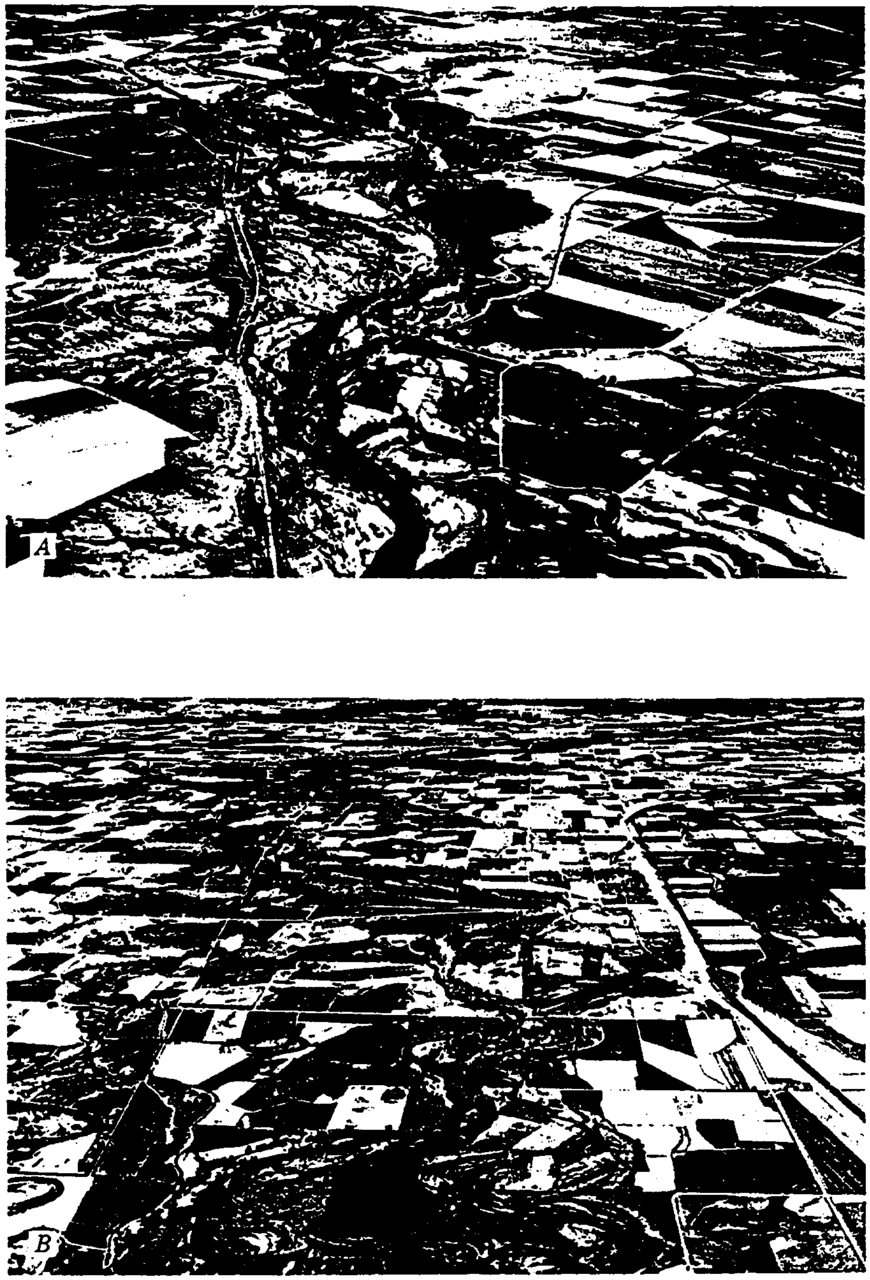

FIGURE 3.—*A*. Aerial view northeastward toward Greeley. The escarpment of the Fox Hills sandstone and the Laramie formation is in the left foreground, the flood plain of the South Platte River is in the center, and the wide, flat surface of the Kersey terrace is on the right. *B*. Aerial view northward toward Platteville. The Kuner terrace is in the left foreground, meander scárs on the flood plain of the South Platte River are in the center foreground, and the Kersey terrace is on the right. Photographs by the U.S. Air Force.

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The Kersey terrace is discontinuous along the west and north sides of the valley but continuous and much more extensive along the east and south sides of the valley. It widens to about 4 miles in the vicinity of Gilcrest and forms the main agricultural area along the South Platte River valley. In some places a gentle slope separates the Kersey terrace from the upland but in other places the upland rises abruptly from the terrace and the break in slope is much more conspicuous.

Along the east side of the South Platte River valley between Denver and Brighton is a broad remnant of a terrace that was formed earlier and is topographically higher than the Kersey terrace; erosion has lowered and dissected this older terrace into a gently rolling surface. On the upland divide along the western and northwestern sides of the South Platte River valley are remnants of old pediments and terraces, formed by ancestral streams that flowed at higher levels than the present-day South Platte and its tributaries. These remnants probably correlate with the features described by Bryan and Ray (1940, p. 20–25) and by Hunt (1954, p. 95–98).

In general, the erosional surface along the west side of the South Platte River valley is steeper and higher than that east of the river; in some places, notably between Welby and Brighton and between the mouths of St. Vrain Creek and the Big Thompson River, an escarpment borders the west side of the flood plain (fig 4).

The divide areas that separate the main river valley from Beebe Draw and the valley of Box Elder Creek are rolling uplands which consist of many small hills and depressions.

The South Platte River valley is about 12 miles wide at the southern boundary of the report area. It decreases to a width of about 6 miles at a bedrock spur in the vicinity of sec. 22, T. 2 S., R. 67 W. and then increases at the south end of Barr Lake. The valley narrows at Brighton and then averages about 2½ miles in width all the way north to the river's confluence with St. Vrain Creek, where it increases abruptly to about 5 miles. The broad segment of the valley extends northeastward to the vicinity of Greeley where the width is again increased even more by the confluence of the South Platte and the Cache la Poudre valleys. From Greeley southeastward, the valley narrows gradually to a width of about 3 miles at Kuner.

The principal northward-trending valleys in the eastern part of the project area, in order from west to east, are Beebe Draw and Box Elder Creek valley. Beebe Draw is ½–2½ miles wide and about 30 miles long, whereas Box Elder Creek valley is 1–4 miles wide

FIGURE 4.—*A*. Aerial view northwestward toward Thornton. The escarpment of the west valley wall is in the background and the South Platte River and the Kersey terrace are in the foreground; *B*. Aerial view of Wildcat Mound. The escarpment of the Fox Hills sandstone and the Laramie formation is in the background and the Kersey terrace and the flood plain of the South Platte River are in the foreground. Photographs by the U.S. Air Force.

and extends from the south boundary of the report area to the South Platte River valley near Kuner, a distance of about 40 miles. The floors of both Beebe Draw and Box Elder Creek valley are irregular surfaces that consist of small knolls and depressions. The valley floors in both valleys consist in places of sand dunes. Stream terraces are not evident in either valley. The valleys, which are roughly parallel in the southern part of the area, merge immediately north of Hudson and then separate again and continue northward.

CLIMATE

The South Platte River basin has moderately cold winters and warm summers. The climate is favorable for the growing of hay and grain and for the raising of livestock. The normal monthly precipitation and temperature at three U.S. Weather Bureau stations are shown graphically in figure 5, and the annual precipitation at the same three stations is shown graphically in figure 6.

The annual precipitation in the project area during the period of record ranged from a maximum of about 23 inches at the Denver city weather station (1909) to a minimum of about 5½ inches at Greeley (1893). The normal annual precipitation at the three weather stations for the base period of record (1921–50) was about 13 inches; two-thirds of that amount fell during the growing season. Precipitation is least during the winter and greatest from April to July. The spring and summer rains, occuring generally as thunderstorms, are erratic and unevenly distributed. Strong winds and hail occasionally accompany the storms. Precipitation is sufficient to support native grasses and shrubs, hay, and some grains, but successful growth of many crops depends on irrigation.

The normal monthly temperature ranges from 24° to 73°F at Greeley, from 26° to 73°F at Fort Lupton, and from 31° to 74°F at the Denver city weather station. The average length of the growing season for the base period of record (1921–50) was about 140 days. The prevailing wind is from the south and its velocity averages about 9.3 miles per hour.

AGRICULTURE AND INDUSTRY

The present agricultural economy of the South Platte River basin is based on irrigation, dry farming, and stock raising. The principal irrigated corps are sugar beets, corn, alfalfa, potatoes, beans, and truck-garden vegetables. Small grains, chiefly wheat, are the principal dry-farm crops. Most of the livestock are beef and dairy cattle, although some hogs, sheep, and poultry are raised.

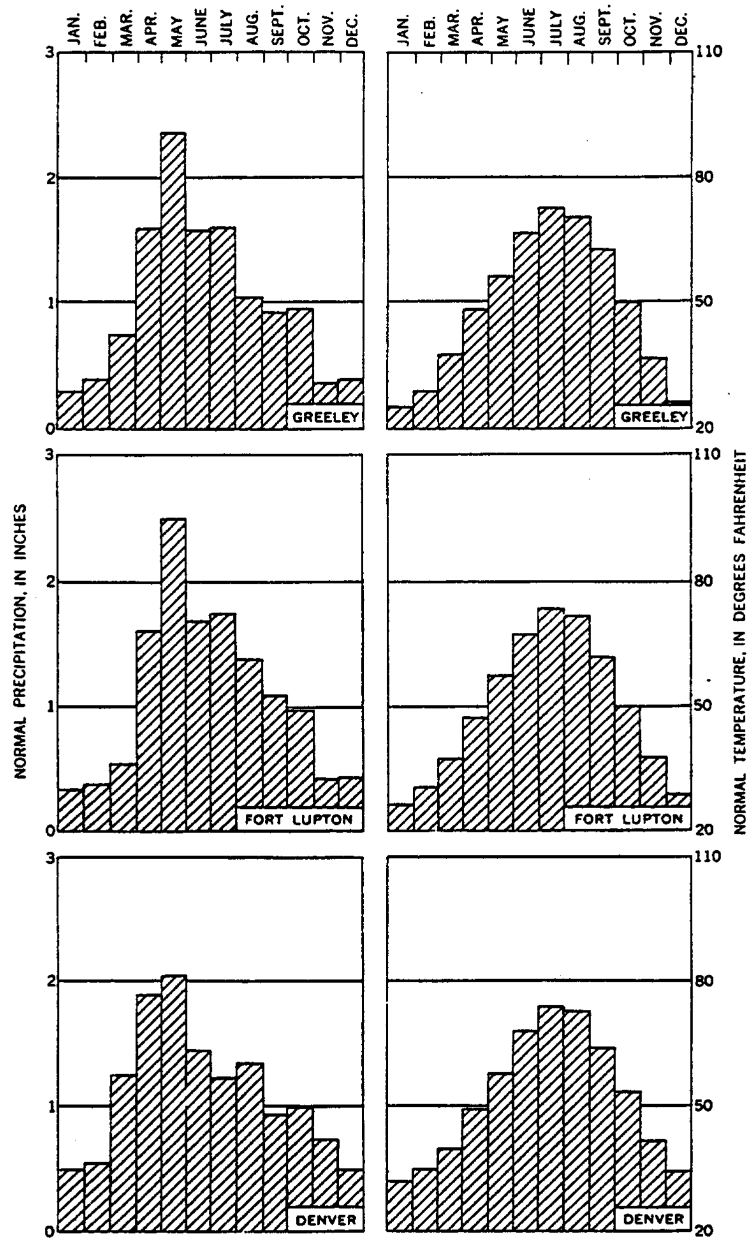

FIGURE 5.—Normal monthly precipitation and temperature for the period 1921–50 at the Denver city weather station, at Fort Lupton, and at Greeley. (Data from U.S. Weather Bureau.)

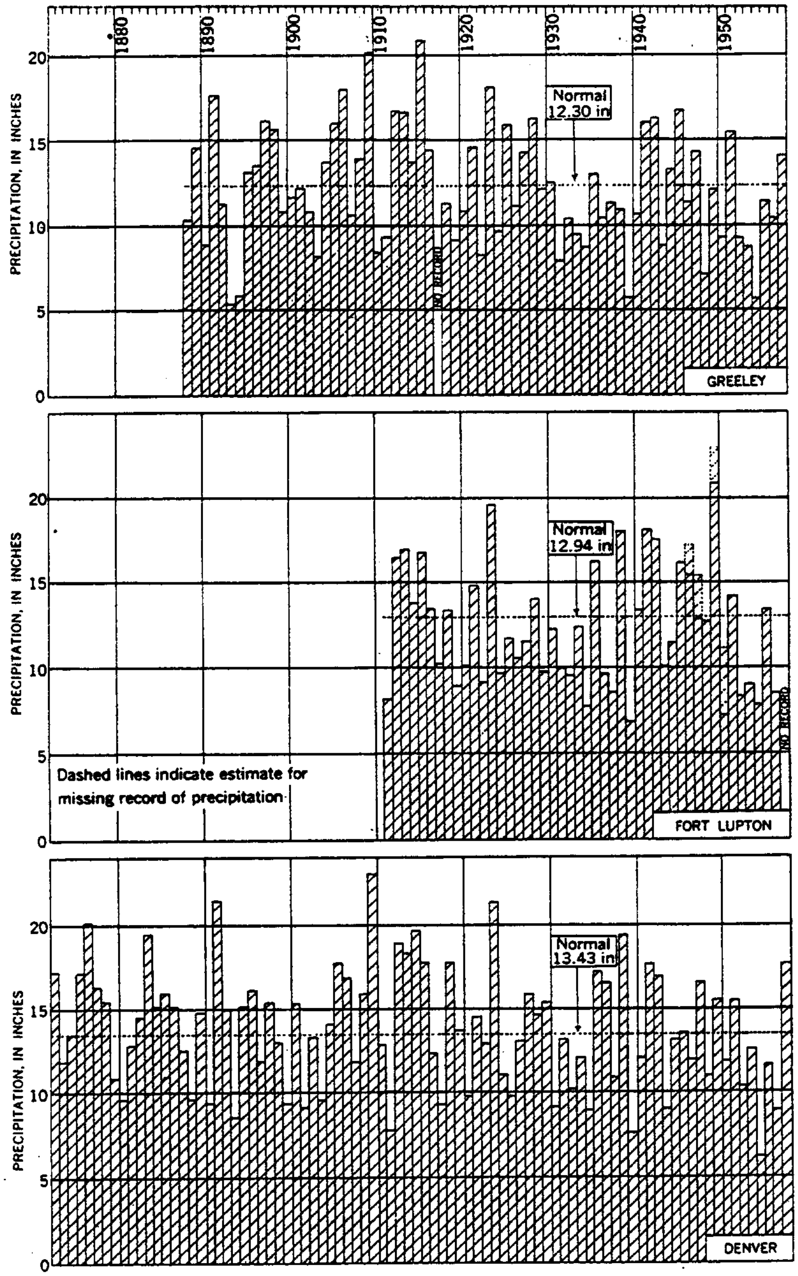

FIGURE 6.—Annual precipitation at the Denver city weather station, at Fort Lupton, and at Greeley. (Data from U.S. Weather Bureau.)

Several large canals, through which water for irrigation is diverted from the major streams, were constructed in the latter half of the 1800's. Water for irrigation is also diverted from several reservoirs constructed around 1900. Because shortages of surface water occur during years of low runoff, irrigation wells have been drilled in the valleys to supplement the surface-water supply. In some areas ground water pumped from wells is the sole supply for irrigation. Probably less than 100 irrigation wells were constructed before 1930, the principal development of ground-water supplies occurring during succeeding periods of drought. By the end of 1957 about 1,650 irrigation wells had been drilled in the report area and the total area under irrigation was about 220,000 acres. Most of the towns and some industries in the area also obtain water from wells. Although nearly all the large-capacity wells are in the valleys, small-capacity domestic and stock wells have been constructed both in the valleys and on the uplands since early settlement of the region. The upland areas that are without adequate surface- or ground-water supplies for irrigation total about 400,000 acres and are used largely for dry farming and for grazing.

The principal industries in the area are related to the processing of agricultural products; they include sugar-beet processing plants, canneries, alfalfa mills, vegetable warehouses, and creameries. A few plants produce construction materials and fertilizers. Deposits of sand and gravel are exploited for the fabrication of concrete products and in building roads.

The area is served by a system of Federal and State highways and improved county roads and by the main lines of the Chicago, Burlington and Quincy and the Union Pacific Railroads (fig. 7). U.S. Highway 85 follows the valley of the South Platte River from Denver through Greeley. U.S. Highways 6 and 34 also serve the area.

GENERAL GEOLOGY

A study of the geology of a region is an important part of a ground-water investigation because the occurrence and movement of ground water and its quantity and quality are directly related to the geology. In this section, therefore, those rock units having the greatest significance in relation to ground-water supplies for irrigation, municipal, and industrial use are discussed in some detail. Brief summaries of the geologic and physiographic history of the area also are given. The thickness, physical character, and water-bearing properties of the stratigraphic units are summarized in table 1.

Rocks at the surface in the report area range in age from Late Cretaceous to Recent. For simplicity, the rocks are divided here into two groups, based on their geologic age, physical characteristics, and

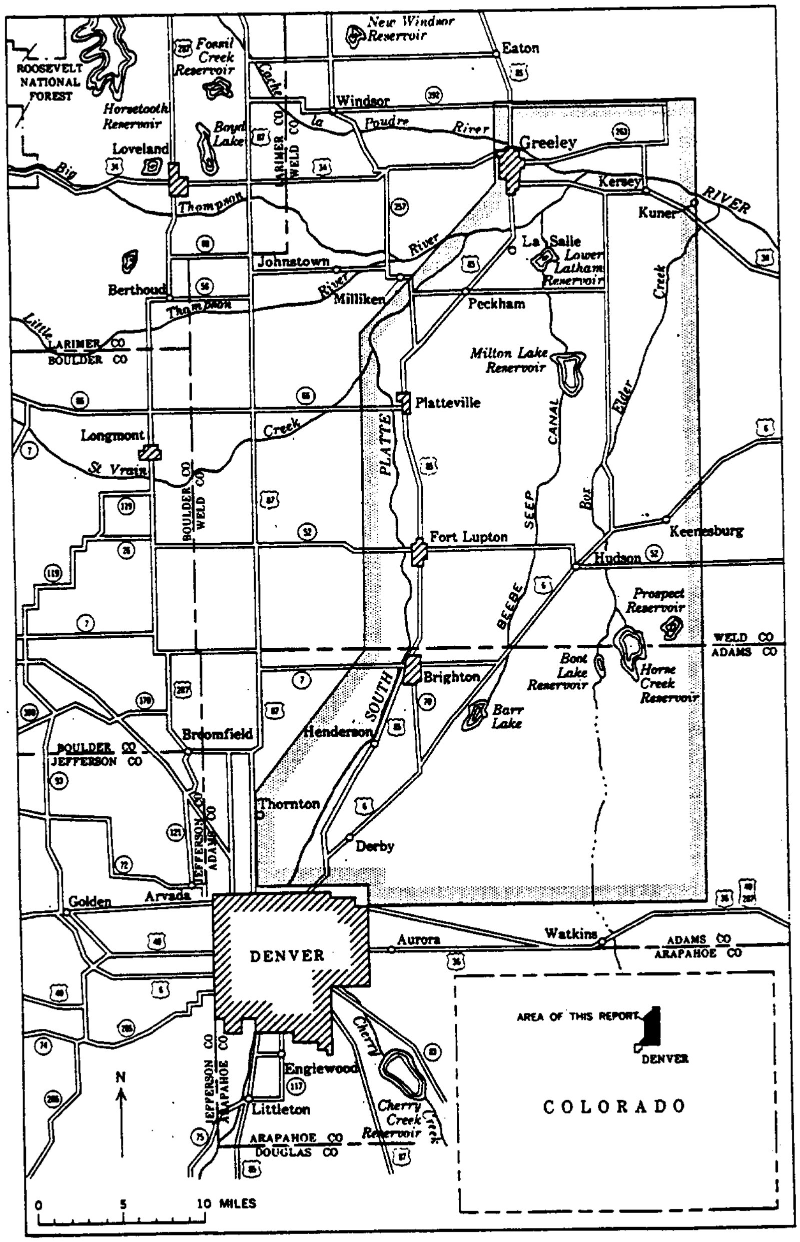

FIGURE 7.—Index map showing the area described in this report.

influence on the occurrence and movement of ground water. One group consists of consolidated rock formations of Late Cretaceous and Tertiary age, here collectively called "bedrock," which crop out in the area at scattered places but are buried throughout the remainder of the area beneath a thin mantle of unconsolidated rock material. The other group consists of unconsolidated sediments that possibly are partly of Tertiary age but are mostly of Quaternary age. These unconsolidated sediments are mostly stream deposits and are thickest where they partly fill valleys that had been cut into bedrock by ancestral streams. Other unconsolidated deposits consist of dune sand, slope wash, and upland deposits. The valley-fill deposits constitute the most productive aquifer yielding abundant supplies of water to most of the wells.

The surface distribution of the mappable rock units is shown on the geologic map (pl. 1), and the subsurface distribution, thickness, and lithology are given by the logs of test holes and wells and by geologic cross sections based on data from the logs (pls. 2 and 3).

BEDROCK FORMATIONS

The report area is underlain by a great thickness of consolidated sedimentary rocks that lie on crystalline rocks of Precambrian age. The formations that do not crop out are not described in detail because they lie at depths that are considered excessive for the present economic development of ground water and because oil-well tests indicate that the water in many of them is of unsuitable quality for general use. The Fox Hills sandstone, the Laramie, Arapahoe, and Denver formations, and the Dawson arkose crop out in the area. Although these formations yield water to many small-capacity wells, they generally are incapable of yielding sufficient quantities for irrigation or other large-scale uses.

The bedrock crops out in the valley walls at some places along the west side of the South Platte River and at various other scattered localities in the report area. In most places, however, the bedrock is mantled by unconsolidated deposits that are called Quaternary upland deposits but are not shown on the geologic map (pl. 1). The bedrock surface, which was produced by erosion, consists of valleys and intervalley highlands. The relief on the bedrock surface is about 550 feet locally and is reflected by the present land surface (pl. 4). Although the bedrock surface slopes north-northeastward, the bedrock formations constituting it dip inward toward the north-south axis of the report area, forming a structural basin. The following discussion of the geology of the bedrock formations is based on a reconnaissance of the principal outcrops in the area and on reports by previous investigators.

TABLE 1.—*Stratigraphic units and their water-bearing properties*

System	Series	Subdivision		Thickness (feet)	Physical character	Water-bearing properties	
Quaternary	Recent and Pleistocene	Dune sand		0-50±	Fine to medium sand and minor amounts of clay and silt.	Serves mainly as medium for recharge from precipitation. Locally yields small quantities of water to domestic and stock wells.	
Quaternary	Recent and Pleistocene	Slope wash		0-30±	Poorly sorted clay, silt, sand, and gravel; grades into valley-fill deposits.	Yields small to moderate quantities of water to domestic and stock wells and to a few irrigation wells.	
Quaternary	Recent and Pleistocene	Valley-fill deposits		0-125+	Interbedded clay, silt, sand, and gravel that contains some cobbles and boulders and beds of altered volcanic ash. Underlies the flood plain and terraces on the South Platte River valley and underlie floor of Beebe Draw and Box Elder Creek Valley. Include some slope wash along the edges of Beebe Draw and Box Elder Valley.	The most important aquifer in the report area and the source of ground water for nearly all the large-capacity wells. Yield moderate to large quantities of water to many domestic, stock, irrigation, public-supply, and industrial wells.	
Quaternary	Pleistocene	Upland deposits		0-15±	Deposits of sand, gravel, conglomerate, and volcanic ash that mantle the bedrock in the upland areas. Include colluvium, residuum, and remnants of pediment and terrace deposits.	Topographically high and well drained. Not a known source of water for wells. Serve as medium for recharge from precipitation.	
Tertiary	Paleocene	Dawson arkose	Denver formation	0-200±	Varicolored clay, soft shale, and siltstone containing much carbonaceous material, interbedded with lenticular poorly sorted generally moderately indurated yellowish-brown sandstone and conglomerate. Locally contains andesitic material and beds of weathered volcanic ash and bentonitic clay.	Yields small quantities of water to domestic and stock wells in the southern part of the report area.	The Dawson arkose, stratigraphically equivalent to part of the Denver and Arapahoe formations, yields small to moderate quantities of water to domestic, stock public-supply, and industrial wells in the southeastern part of the report area.
Cretaceous		Dawson arkose	Arapahoe formation	0-600±	Upper part (400 ft.): Soft predominantly blue or gray sandy to clayey shale and clay and a few lenticular beds of sandstone. Lower part (200 ft.): White to yellow sand, gravel, and conglomerate, variously indurated and including minor amounts of shale and clay.	Yields small to moderate quantitites of water to domestic, stock, public-supply, and industrial wells in the southern part of the report area.	

Cretaceous	Upper Cretaceous	Laramie formation	0-600±	Upper part (400 ft.): Chiefly olive-gray silty shale and siltsone, and lenticular silty sandstone; contains numerous carbonaceous clay beds and lignitic seams. Lower part (200 ft.): At top, a sequence of thin beds of blue-gray silty shale, sandstone, and lignitic material. At bottom several relatively thin beds of sandstone, fairly thick beds of subbituminous coal, and several other thinner sandstone units that locally coalesce with the thick basal sandstone.	Some of the sandstone units in the upper part yield small to moderate quantities of water to domestic, stock, and industrial wells throughout the report area. The basal sandstones in the lower part yield small to moderate quantities of water to domestic, stock, public-supply, and industrial wells throughout the area.
		Fox Hills sandstone	0-250±	Uniformly bedded buff to pale-yellow friable medium-grained sandstone interbedded with gray to black silty shale and silty sandstone. About 50-60 feet of massive sandstone at top.	Yields small to moderate quantities of water to domestic, stock, public-supply, and industrial wells throughout the report area.

The oldest formation cropping out in the area is the Fox Hills sandstone of Late Cretaceous age. It underlies the entire report area but is in direct contact with the unconsolidated rock formations only in T. 4 N., R. 67 W. (Mather and others, 1928, pl. 14). The formation crops out at Wildcat Mound (secs. 23 and 26, T. 4 N., R. 67 W.) and along the northwest wall of the South Platte River valley between the valleys of St. Vrain Creek and the Big Thompson River.

The Fox Hills sandstone consists mainly of marine sandstone interbedded with sandy shale. The lower part of the formation consists of a sequence of sandstone layers interbedded with gray to black carbonaceous silty shale. The sandstone is mostly medium grained, buff to pale yellow, and poorly consolidated, and it contains calcareous and ferruginous material. Some of the sandstone beds contain large hard sandy concretions. At several horizons are massive beds of fine-grained firmly cemented sandstone that range in color from white to greenish yellow. One such bed, which forms the upper part of the formation, is persistent and generally is about 50–60 feet thick.

The bottom and the top of the formation are not marked by sharp breaks. Lovering and others (1932, p. 702–703) stated:

> The base of the Fox Hills formation shall be considered as the horizon below which the section is predominantly gray marine clay shales and sandy shales of Pierre age, and above which the section changes rapidly to a buff to brown [marine] sandstone containing numerous large gray to brown, hard, sandy concretions. This lower concretionary member is commonly overlain by a series of light-gray to brown [marine] sandstones and sandy shales.
>
> The top of the Fox Hills formation shall be considered as the horizon above which the section is composed predominantly of fresh- and brackish-water deposits accompanied by coals and lignitic shales, and below which it is predominantly marine.

Mather, Gilluly, and Lusk (1928, p. 93–99) described measured sections and fossils from the Fox Hills sandstone, and Lovering and Goddard (1950, p. 40) considered its thickness to be about 250 feet. In the western part of the report area the formation dips slightly toward the east, but in the eastern part of the area it dips toward the west.

Conformably overlying the Fox Hills sandstone is a series of beds of fresh- and brackish-water shale, sandstone, and coal. These beds constitute the Laramie formation of Late Cretaceous age. The contact between the Fox Hills and the Laramie formations is a transition zone of alternating marine and nonmarine strata. The Laramie formation underlies all the report area except the northwestern corner where it has been removed by erosion; it is overlain by thin upland deposits in most of the area north of the base line. Generally the formation is poorly exposed in the report area because it is covered by younger bedrock formations and by mantle rock throughout most of

the area; it crops out at Wildcat Mound (fig. 8) and in secs. 12 and 13, T. 2 N., R. 65 W.

The Laramie formation consists of two parts, a lower part composed predominantly of sandstone and an upper part composed largely of shale. Both contain beds of coal, but the coal beds in only the lower part are of economic importance. The formation contains abundant plant remains throughout (Darton, 1905, p. 111).

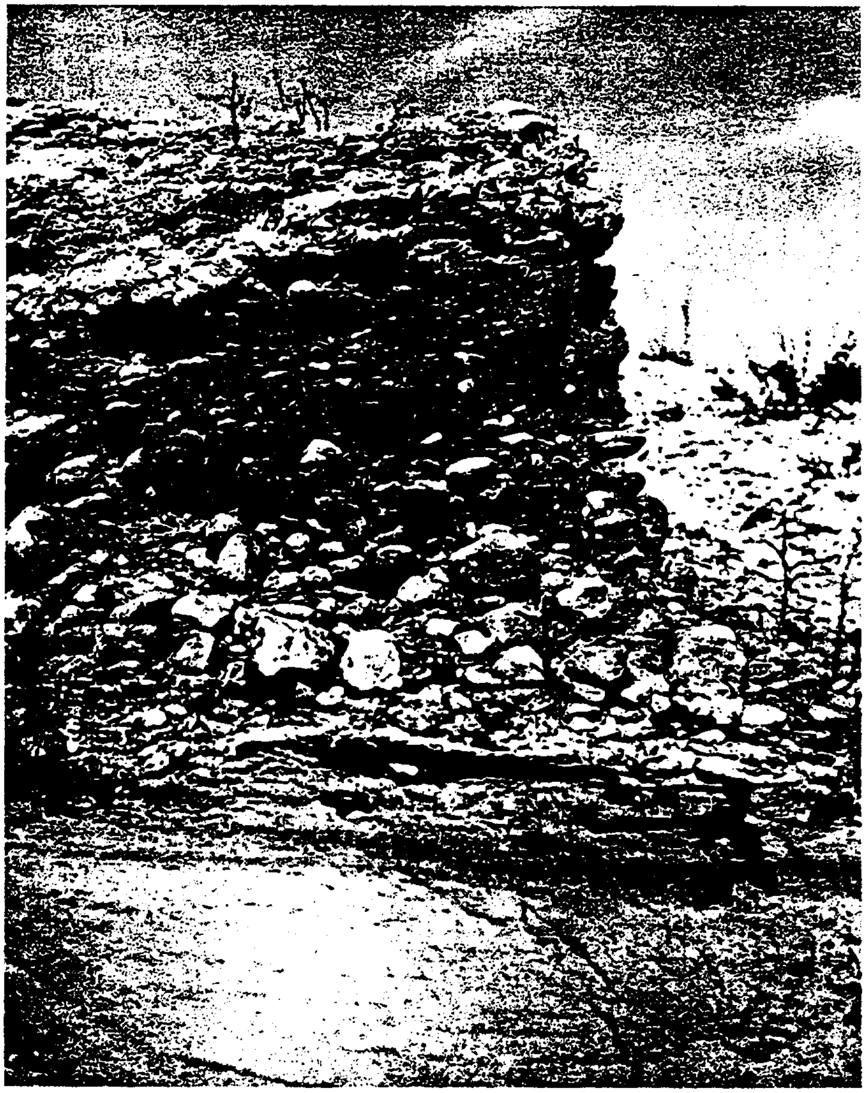

FIGURE 8.—Light-colored massive sandstone of the Laramie formation overlain by conglomerate at Wildcat Mound. The conglomerate is 3 feet thick and contains cobbles as large as 5 inches in diameter. Outcrop is in NE¼NE¼NW¼ sec. 26, T. 4, N., R. 67 W. Photograph by R. S. Cary, Jr.

The lower 200 feet of the Laramie consists of beds of carbonaceous blue-gray silty shale, fairly thick beds of subbituminous coal, and buff to yellow or white loosely cemented beds of sandstone. The sandstones predominate, especially near the base of the lower part; the most persistent is a thick bed of medium-grained white quartzitic sandstone, which is designated the "B" sandstone (Emmons and others, 1896, p. 73–74). Locally, other thinner beds of white to yellow sandstone coalesce with the B sandstone. Some of the sandstone contains ferruginous and calcareous material and large hard concretions, and in some places beds of sandstone contain mollusk shells. The shale and sandstone near the top of the lower part are silty and contain some thin seams of lignite.

The upper part is a series of beds of buff to olive-gray clay, shale, and siltstone. This series of beds contain lenses of sandstone and thin beds of lignite. Many ironstone concretions and some seams of fissile coal also are present in the upper division.

Owing to erosion, the thickness of the Laramie formation ranges from 0 in places in the northwestern part of the area to about 600 feet in the southern part. In the western part of the area the formation dips gently toward the east, but in the eastern part the dip is reversed and is slightly toward the west. The top of the formation, which is an uneven erosional surface, is overlain by unconsolidated Quaternary deposits in the northern part of the area and by consolidated rocks of Late Cretaceous and Tertiary age in the southern part.

The Arapahoe formation of Late Cretaceous age and the Denver formation of Late Cretaceous and Paleocene age overlie the Laramie formation in the southern part of the report area (pl. 1). These formations are of continental origin and include material derived from the older formations in the area. Both formations contain abundant fossils of plants and animals. A discussion of the age of the formations based on fossil assemblages is given by Lovering and Goddard (1950, p. 41). The eroded surface of both formations is mantled by unconsolidated deposits in most places and both formations crop out at scattered places in the banks of streams and on hilltops.

The lower 200 feet of the Arapahoe formation consists of white to yellow sandstone and conglomerate and some thin local beds of shale and clay. The sandstone and conglomerate are poorly to moderately well indurated, and they are finer grained in the eastern part of the area. The upper two-thirds of the formation differs markedly from the lower third, consisting predominantly of beds of soft sandy blue or gray shale and clay that contain a few lenses of sandstone and concretions of ironstone. The thickness of the formation ranges from 0 to about 600 feet in the report area.

The Denver formation unconformably overlies the Arapahoe formation and has a smaller areal extent. It consists of light-gray, bluish-gray, and brown clay, soft shale and siltstone interbedded with poorly sorted generally moderately indurated yellowish-brown lenticular sandstone and conglomerate. The clay, shale, and siltstone contain much carbonaceous material, and all the formation, especially the lower part, contains tuffaceous material and fragments of andesitic rocks. In some places a few beds of bentonitic clay are present. Only the lower part of the formation, which ranges in thickness from 0 to about 200 feet, remains in the southwestern part of the report area.

The Dawson arkose is more than 2,000 feet thick several miles southeast of the project boundary. In the southern part of the project area the Dawson arkose is intertongued with the Laramie and Arapahoe formations. It is also intertongued with the Denver formation in the southwestern part of the project area. Logs of wells and test holes indicate that the Laramie and Arapahoe formations and the Dawson arkose are intertongued along Box Elder Creek from the southern boundary of the report area to the vicinity of Keenesburg. According to Lovering and Goddard (1950, p. 41), the lower part of the Dawson arkose contains flora and fauna of Cretaceous age and the upper part contains a Paleocene flora.

Stratigraphically, the Dawson arkose is equivalent to the Denver and Arapahoe formations. The formation consists of white to red arkosic grit, sand, gravel, conglomerate, and micaceous sandstone with interbedded gray, yellow, red, or green clay and shale. The rocks in outcrops generally are altered to white, yellow, or red by weathering. The formation contains abundant amounts of andesitic material locally. Rhyolite flows, rhyolitic tuffs, and cobbles and boulders occur in the upper part. Locally, the formation is well indurated, often with ferruginous cement, but the degree of induration differs greatly from place to place. The thickness of the formation in the report area ranges from a few hundred to about 900 feet.

UNCONSOLIDATED DEPOSITS

In the report area the unconsolidated sediments of Quaternary age include upland deposits, valley-fill deposits, slope wash, and dune sand. Although these deposits mantle the bedrock in most places, the areal distribution of only the principal valley-fill, dune-sand, and slope-wash deposits is shown on plate 1. The valley-fill deposits are the most important source of ground water for large-capacity wells.

The upland deposits of Quaternary age include remnants of terrace deposits, pediment veneer, colluvium, and residuum that are topographically higher than the terraces in the river valley. Because

these deposits generally form only a relatively thin mantle on the bedrock surface and in most places their boundaries are not readily delineated, they are not shown on plate 1. In a few places along the west side of the river valley the mantle consists of a few feet of conglomerate. Figure 8 shows the conglomerate capping Wildcat Mound. The origin of the upland deposits has been determined in a general way but probably the terrace deposits and pediment veneer were laid down by streams, the colluvium accumulated by the transporting action of gravity, and the residuum was formed by the disintegration of rock materials without subsequent transportation. Hunt (1954, pl. 3) mapped and described these deposits in the vicinity of Denver.

The valley-fill deposits of Quaternary age underlie the following topographic units in the South Platte River valley: (1) An old and partly dissected terrace, (2) the Kersey terrace, (3) the Kuner terrace, and (4) the flood plain. In addition, valley-fill deposits underlie the floor of both Beebe Draw and the Box Elder Creek valley.

The old terrace, which is immediately above the Kersey terrace along the east side of the South Platte River valley, decreases in width from about 10 miles at the southern boundary of the report area to a wedgeout near Brighton. Erosion by ephemeral and intermittent streams has dissected the surface into a gently rolling topography and, in secs. 25, 35, and 36, T. 2 S., R. 67 W., the tops of bedrock hills stand above the general level of the old terrace. The eastern boundary of the terrace is indistinct because the valley-fill deposits underlying the terrace grade imperceptibly into slope-wash deposits, into the valley-fill deposits in the small tributary valleys in T. 2 S., R. 66 W., and into the valley-fill deposits in Beebe Draw. For this reason, the valley-fill deposits underlying the old terrace were not mapped as a unit but were included in the material mapped as alluvium (Qal on pl. 1). The valley-fill deposits beneath the old terrace consist of gravel and sand having a high percentage of clay and silt. The material generally is fairly well sorted, except near the uplands where it grades into the poorly sorted slope-wash deposits.

The unconsolidated material underlying the Kersey and Kuner terraces, the flood plain in the South Platte River valley, and the valley floors of Beebe Draw and the Box Elder Creek valley constitutes the principal valley-fill deposits. The Kersey and Kuner terraces are well developed throughout the river valley, especially along the east side, and they extend up the western tributary valleys. Terraces beneath the level of the Kuner terrace border the flood plain of the river, but they are so nearly the same height above the river as the flood plain that they are barely distinguishable from it. Therefore, the valley-fill deposits underlying the lower terraces and the flood plain

were mapped as one unit (Qal). This unit includes also the valley-fill deposits underlying the floor of Beebe Draw and the Box Elder Creek valley. The valley-fill deposits consist mainly of sand and gravel but contain lenses and beds of silt and clay and a lower bed of cobbles and boulders; included in the valley-fill deposits are miscellaneous rock types such as granite, quartzite, gneiss, schist, sandstone, and volcanic rocks. The sand and gravel particles generally are well rounded to subrounded, and exposures in gravel pits and steep slopes show crossbedding. In many places, the bodies of clay are thick and extensive. Bryan and Ray (1940, p. 48–49) and Hunt (1954, p. 117–124) described fossils and artifacts that were found in the valley-fill deposits in the South Platte River valley.

A bed of coarse material, which consists mainly of cobbles and boulders, was found in the drilling of some wells and test holes in Beebe Draw. The bed, which ranges in thickness from a few feet to at least 35 feet, immediately overlies the bedrock and everywhere is overlain by finer grained sediments. In Tps. 1 and 2 S., R. 66 W., in the South Platte River valley, a bed of altered volcanic ash revealed by microscopic examinations of test-hole samples is interbedded with a bed of coarse material. The coarse material and the volcanic ash are believed to be of pre-Wisconsin age. The deposits underlying the Kersey and Kuner terraces, however, are fluvioglacial outwash that was deposited during the Wisconsin glacial stage. The deposits beneath the terraces range in grain size from clay to medium gravel and contain some coarse gravel. Directly underlying the flood plain of the South Platte River to a depth of about 10 feet is Recent alluvium consisting of material eroded from the upper end of the drainage basin of the river and of reworked valley-fill material, all of which ranges in grain size from clay to boulders.

In Beebe Draw, the lower beds of coarse-grained valley fill and the altered volcanic ash are overlain by finer grained sediments. The deposits that underlie the floor of the Box Elder Creek valley mainly are fine to medium sand that contains beds and lenses of silt, clay, and fine to medium gravel. These deposits, for the most part, are finer grained than those in the valley fill in the South Platte River valley and Beebe Draw, apparently because Box Elder Creek has never had sufficient material-carrying competence to transport and deposit cobbles and boulders as far downstream as the report area. Formations in the area drained by the headwaters of Box Elder Creek contain abundant cobbles and boulders.

Available data on physiography and petrology are insufficient to permit the correlation of the valley-fill deposits in Beebe Draw and the Box Elder Creek valley with those in the South Platte River valley. For this reason and because the upper part of the valley-fill deposits

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in Beebe Draw and in the valley of Box Elder Creek are of Recent age, the deposits in these two tributary valleys are shown as alluvium on plate 1.

The contours on the surface of the bedrock (pl. 4) and the geologic cross sections (pls. 2 and 3) show the location, size, and shape of the ancestral channels that contain the valley-fill material. In general, the old channels conform to present drainage patterns. The approximate thickness of the fill in the valleys can be determined by subtracting the altitude of the bedrock surface (pl. 4) from the altitude of the land surface. In the South Platte River valley, the thickness of the valley fill ranges from 0 along the edge of the valley to as much as 125 feet in the thickest part. The valley-fill deposits underlying the floor of Beebe Draw average about 85 feet in thickness along the center part of the draw and thin to a featheredge along the margins. The average thickness of the valley-fill deposits in the axial part of the Box Elder Creek valley is about 70 feet.

The slope-wash deposits that fringe the valley fill in the South Platte River valley, Beebe Draw, and Box Elder Creek valley consist of angular gravel and sand interbedded with clay and silt. They feather out against the upland areas, but lap onto and are intertongued with the rounded material in the stream-deposited valley fill and were mapped as slope-wash deposits; however, along the sides of Beebe Draw and the Box Elder Creek valley, where the slope wash forms long gentle slopes and grades imperceptibly into the valley-fill deposits, the slope wash was included in the unit mapped on plate 1 as alluvium (Qal). In most places the slope wash and valley fill probably were deposited contemporaneously. The thickness of the slope wash is indeterminate because the slope wash is intertongued with the valley-fill deposits.

Dune sand of late Pleistocene and Recent age mantles the vally-fill deposits and bedrock in many parts of the report area, but only the most important and distinctive deposits are shown on plate 1. The largest deposit is in the upland area north of Keenesburg, where the sand dunes extend from the upland onto the valley floor of Box Elder Creek. A well-defined deposit overlies the valley-fill deposits north of Hudson where Beebe Draw and the Box Elder Creek valley merge; another deposit mantles the valley-fill deposits in Beebe Draw immediately north of Milton Reservoir. The dunes have a northwesterly trend paralleling the direction of the prevailing winds during Late Pleistocene and Recent time. Older deposits of dune sand, which commonly are more subdued in topographic form and covered with vegetation, mantle the upland areas at many other places in the eastern part of the report area. The dune sand in the report area is fine to medium and in many places is mixed with clay and silt. The maximum thickness of the sand deposits is not known but it may be as much as 50 feet where the dunes are well developed.

GEOLOGIC AND PHYSIOGRAPHIC HISTORY

The part of the South Platte River basin included in this study is in the southern part of a large structural basin, the so-called Denver-Julesburg basin, which extends from the vicinity of Pueblo across northeastern Colorado into southwestern Nebraska and southeastern Wyoming. Most of the consolidated sedimentary rocks underlying but not cropping out in the report area are exposed along the east side of the Front Range of the Rocky Mountains. The oldest formation that crops out in the report area is the Fox Hills sandstone of Late Cretaceous age. The events before Fox Hills time are discussed only briefly in this report, whereas the events during and after Fox Hills time are emphasized. It was these later events that produced the principal geologic features that control the occurrence and movement of ground water.

The following discussion of the geologic and physiographic history of the region is taken largely from reports by Bryan and Ray (1940), McLaughlin (1946), Hunt (1954), and Bjorklund and Brown (1957) but in part from field observations that were made during this investigation. Data on the sedimentary rocks that underlie but do not crop out in the report area are based on interpretations of the logs of deep oil-test holes in and near the area (Blair, 1951) and on examinations of outcrops of these rocks in nearby areas. A generalized section of the geologic formations exposed in the report area is given in table 1 and a geologic time scale is shown in table 2. Descriptions of the stratigraphic units and their water-bearing properties are given in table 1.

TABLE 2.—*Major stratigraphic and time divisions in use by the U.S. Geological Survey*

[Prepared by the Geologic Names Committee, 1958. Terms designating time are in parentheses. Informal time terms early, middle, and late may be used for the eras, and for periods where there is no formal subdivision into Early, Middle, and Late, and for epochs. Informal rock terms lower, middle, and upper may be used where there is no formal subdivision of a system or of a series]

Era	System or period	Series or epoch	Estimated ages of time boundaries in millions of years [1]
Cenozoic	Quaternary	Recent	
		Pleistocene	1
	Tertiary	Pliocene	10
		Miocene	25
		Oligocene	40
		Eocene	60
		Paleocene	

See footnote at end of table.

TABLE 2.—*Major stratigraphic and time divisions in use by the U.S. Geological Survey*—Continued

Era	System or period		Series or epoch	Estimated ages of time boundaries in millions of years [1]
Mesozoic	Cretaceous		Upper (Late) Lower (Early)	
				125
	Jurassic		Upper (Late) Middle (Middle) Lower (Early)	
				150
	Triassic		Upper (Late) Middle (Middle) Lower (Early)	
				180
Paleozoic	Permian			
				205
	Carboniferous systems	Pennsylvanian	Upper (Late) Middle (Middle) Lower (Early)	
		Mississippian	Upper (Late) Lower (Early)	
				255
	Devonian		Upper (Late) Middle (Middle) Lower (Early)	
				315
	Silurian		Upper (Late) Middle (Middle) Lower (Early)	
				350
	Ordovician		Upper (Late) Middle (Middle) Lower (Early)	
				430
	Cambrian		Upper (Late) Middle (Middle) Lower (Early)	
				510
Precambrian			Informal subdivisions such as upper, middle, and lower, or upper and lower, or younger and older may be used locally	
				3, 000

[1] Age values given are the Holmes "B" time scale points (Holmes, A., 1947, The construction of a geological time scale: Geol. Soc. Glasgow, Trans. v. 21, pt. 1, p. 145). Dates are rounded to the nearest 5 million years. The errors are unknown, but more recent age determinations by various physical methods are in general agreement with these values.

PALEOZOIC AND MESOZOIC ERAS

Precambrian basement rocks in the report area are unconformably overlain by marine deposits of coarse poorly sorted conglomerate, arkosic sandstone, and silty to sandy shale. These deposits were derived from highlands to the west and were deposited in the shallow

basin that bordered the highlands during Pennsylvanian time. The basin continued to subside and to receive additional sediments until the end of Pennsylvanian time, when the sea withdrew. An arid climate then developed, and thick sequences of red beds and evaporite deposits were laid down during Permian time.

During the Triassic period, shallow lakes and sluggish streams were formed. These streams meandered over a large featureless plain depositing their loads of sand and silt. Triassic time ended with regional uplift and resulting erosion. This erosion continued into the Jurassic period.

During the Jurassic period, continental conditions prevailed and fresh-water sand, clay, and limestone were deposited. The abundance of dinosaur and other fossil remains indicate that animal life flourished under a mild climate.

During Early Cretaceous time, shallow-water sediments were deposited in a transgressing and regressing sea and in swamps and lagoons (Dakota group). During much of Late Cretaceous time there were widespread invasions of the sea and several thousand feet of marine limestone, shale, and sandstone (Benton shale, Niobrara formation, Pierre shale, and Fox Hills sandstone) were deposited. Near the close of the Cretaceous period the area now occupied by the Rocky Mountains began to rise, the shoreline of the sea alternately advanced and retreated, and the sandstone, shale, and coal of the lower part of the Laramie formation were deposited. Then the Cretaceous sea retreated and the area was occupied by extensive bodies of brackish and fresh water in which were deposited the sandstone, shale, and carbonaceous material that compose the upper part of the Laramie formation. The continued rise of the Rocky Mountains increased the gradients of streams and the beds of coarse clastic materials that compose the lower part of the Arapahoe formation and the Dawson arkose were deposited. Subsequently, when stream gradients were decreased and lakes and swamps formed in the Denver area, the sandstone, shale, and clay of the middle part of the Dawson arkose and the upper part of the Arapahoe formation were deposited. Near the close of Cretaceous time, uplift again was accelerated and streams of increased gradient deposited the coarse sediments that compose the lower part of the Denver formation. The Cretaceous period ended with extensive mountain building.

CENOZOIC ERA

TERTIARY PERIOD

During Early Tertiary time the Rocky Mountain region was uplifted and eroded repeatedly. During Paleocene time the predominantly clastic material composing the upper part of the Denver

formation and the Dawson arkose was derived from the Rocky Mountains to the west and deposited by streams and in lakes. The sediments consisted of conglomerate, arkosic sandstone, siltstone, shale, and volcanic debris from the extensive volcanism in the region. During Middle and Late Tertiary time, sheetlike beds of clay, silt, sand, and gravel were deposited over most of the region. These beds, which compose the White River group and the Ogallala formation, probably extended over much of the report area in Late Tertiary time. At the end of Tertiary time and during Early Quaternary time, the area was extensively eroded and, in the report area, the entire White River group and the Ogallala formation and the upper part of the underlying formations were removed.

QUATERNARY PERIOD

During Early Pleistocene time, the continued uplift of the Rocky Mountains and an increase in precipitation rejuvenated the streams in the region. A succession of pediment surfaces were formed, and then the pediments and the underlying consolidated rock formations were extensively eroded, and deep valleys were formed (Bryan and Ray, 1940, p. 20–27). Studies by Hunt (1954, p. 131) indicate that by Middle Pleistocene time a drainage system, which mainly conforms to the present drainage pattern, was well established and the main valleys were cut into the bedrock about as deep as they are today. The location, size, and areal extent of the ancestral valleys are shown on plate 4 by contour lines that depict the surface of the bedrock.

During a period of downcutting in the high mountain areas to the west, fluvioglacial materials were deposited in the valleys of the report area. Deposits composed predominantly of cobbles and boulders form the bottom part of the valley fill in Beebe Draw. The physical character of these deposits and the drainage pattern shown on the bedrock contour map suggest that during Middle Pleistocene time the ancestral South Platte River flowed through the valley now occupied by Beebe Draw. Although the material in the upper part of the valley fill in Beebe Draw is fine grained, the lower part is coarse grained and consists of rock types that were derived from the Rocky Mountains. The coarse-grained material is interbedded with altered volcanic ash and it may have been deposited contemporaneously with similar deposits of Kansan age in the Denver area. Had Beebe Seep drained only the small area that it now drains, the valley-fill sediments would be finer grained and would be composed only of material derived from the consolidated rocks of Cretaceous and Tertiary age in its present drainage basin.

The South Platte River abandoned its course through Beebe Draw when it was captured by a tributary of the ancestral Cache la Poudre

River. The small low-gradient tributary was able to capture the large high-gradient stream, which was coming from the Rocky Mountains, by headward erosion in the relatively soft shale and sandstone of the Laramie and Fox Hills formations. After the change in course, the South Platte River eroded the deep valley it now occupies.

The history of the Box Elder Creek valley is not well known. Apparently the reach south of Hudson was a tributary of the ancestral South Platte River during Early or Middle Pleistocene time, and after the capture of the river, Box Elder Creek continued to flow through the lower reach of Beebe Draw. Probably a headward-eroding tributary from the north captured Box Elder Creek near Hudson and diverted the stream from Beebe Draw into the valley it now occupies. The absence of cobbles and boulders in the valley-fill deposits in the lower reach of the Box Elder Creek valley indicate that the stream piracy occured after the deposition of the coarse materials in Beebe Draw.

After a period of downcutting, the South Platte River valley was partly filled with coarse fluvioglacial material derived from the Rocky Mountains. These sediments, which form the lower part of the valley-fill deposits, consist of gravel containing abundant cobbles and boulders; they are of post-Kansan to Early Wisconsin age (Hunt, 1954, p. 98–101) and are overlain by younger deposits.

During subsequent glacial and interglacial stages in the Rocky Mountains, cycles of deposition and downcutting by the streams left the terrace deposits that now extend down the valley of the South Platte River and part way up the valleys of its western tributaries. Glaciation during Wisconsin time is reflected by the Kersey and the Kuner terraces, which are remnants of a valley fill that was built to a much higher level than the present bed of the river, and which were partly dissected when the river cut down. The reason for the position of the river and its flood plain along the western side of the valley fill is not known.

Erosion of the uplands, local deposition of slope wash and alluvium, and reworking of the flood-plain alluvium have been the principal active geologic processes during Recent time. There were several periods of minor alluviation and downcutting in the South Platte River valley during which low terraces were formed, broad alluvial fans were built in some places over the older terraces, and arroyos were cut through the older deposits by some of the tributary streams. During Late Pleistocene and Recent time the valleys of Beebe Draw and Box Elder Creek were not eroded significantly. Instead, the meandering trunk streams and small tributary streams covered the valley-fill deposits of Early Pleistocene age with a layer of relatively fine grained alluvium. Deposition of the slope wash that borders the

South Platte River valley probably has been continuous during Pleistocene and Recent time. Logs of the test holes and wells drilled in the slope wash (pls. 2 and 3) show that fine-grained material in the slope wash extends into the Pleistocene and Recent valley-fill deposits.

The dune sand and silt that mantle much of the area were deposited during Late Pleistocene and Recent time (Hunt, 1954, p. 108 and 132). The eolian material was derived from the flood plains of the streams and exposed consolidated rock formations; the alinement of the dunes suggests that the prevailing winds were from the northwest. In most places the dunes are covered with vegetation and are no longer migrating.

GROUND WATER

Only a general discussion of the characteristics of ground-water behavior and the definitions of ground-water terms is given in this section. More detailed discussions are given in succeeding sections on "Hydrologic properties of water-bearing formations" and "Ground-water conditions and utilization in the valleys."

Because the unconsolidated valley-fill deposits contain the most abundant supply of ground water for large-capacity wells, they are emphasized in this discussion.

GENERAL FEATURES OF OCCURRENCE

The ultimate source of all ground water in the South Platte River basin is precipitation. Part of the snowmelt and rain is carried off by the streams, part evaporates, and the remainder infiltrates the ground. The water that is not consumed by vegetation or held by molecular attraction moves downward and is added to the zone of saturation (the zone saturated with water under hydrostatic pressure) in the soil or rocks. Water in the zone of saturation percolates laterally through the more permeable consolidated rock formations and through the unconsolidated rock materials that overlie the bedrock, ultimately discharging at the surface through wells, seeps, and springs or by evapotranspiration. The principal bodies of ground water within the report area are recharged chiefly by subsuface inflow though the unconsolidated rock materials, by seepage from streams, reservoirs, canals, and irrigated tracts, and by infiltration of precipitation falling directly on the basin. The underflow from adjacent consolidated rocks may contribute minor amounts of recharge. Ground water is discharged naturally from the report area through springs and seeps, by evapotranspiration, by subsurface outflow and, artificially, from wells. In general, during a long period of years, if ground water is not being depleted by overpumping, the quantity of discharge is equal to the quantity of recharge.

Where ground water is confined under pressure between two impermeable formations, it is termed "confined" or "artesian" ground water. If a well is drilled through the upper impermeable layer and any unconfined water above that impermeable layer is cased out, water will rise in the well to a height corresponding to the pressure head of the confined ground water. The pressure head depends on the difference in altitude between the intake and discharge areas on the loss of head caused by friction as the water moves through the aquifer. Where the pressure is sufficient to raise the water in the well above the land surface, the well will flow and is termed a "flowing artesian well." The pressure head of a body of confined ground water defines a regional imaginary surface, the "piezometric surface," which is analogous to a regional water table but whose level may be greatly different from that of the water table in the same area. The difference in water levels is especially significant if the confined aquifer is recharged in a distant outcrop area. In areas where ground water generally is under water-table conditions, a relatively impermeable layer of small areal extent, such as a bed of clay, may cause the ground water to be confined locally.

The amount of water that can be stored in a formation depends upon the porosity of the rock material. Porosity is expressed as the ratio of the aggregate volume of the open spaces to the total volume of the rock material. Although the capacity of a rock material to store water is determined by its porosity its capacity to transmit and yield water is dependent upon its permeability. The permeability of a rock material may be defined as its capacity for transmitting water under hydraulic head, and it is measured by the rate at which the material will transmit water through a given cross section under a unit difference of head per unit of distance. Deposits of sand and gravel and porous consolidated rocks are permeable if the open spaces in them are connected and are large enough to allow water to move relatively freely through them under the force of gravity.

Although deposits such as dense silt or clay commonly have a high porosity, they transmit water slowly because of the small size of the open spaces.

THE WATER TABLE

SHAPE AND SLOPE

The regional water table in an area is defined by water levels in wells tapping unconfined (water-table) aquifers. A water-table contour map (pl. 5) was prepared from records of water-level measurements made in 350 wells during the first part of November 1957. The contour lines pass through points of equal elevation on the water table and show the position and configuration of the water table at

the time the measurements were made. In general, the direction of ground-water movement is downgradient at a right angle to the contour lines. The water moves from points or areas of recharge toward points or areas of discharge. The gradient of the water table is governed by the rate of flow, the thickness and permeability of the rock materials through which the water moves, and the configuration of the surface of the underlying bedrock formations. The gradient needed to move a given amount of water from a point of recharge to a point of discharge is greater in materials of low permeability than in materials of high permeabilty.

Irregularities in the shape and slope of the water table may be caused by any of the following: local differences in gain to or loss from the ground-water reservoir, differences in the thickness and permeability of the rock materials, and irregularities in the shape of the bedrock floor. Heavy pumping for irrigation, municipal, and industrial water supplies may create local depressions in the water table, and transpiration by vegetation may lower the water table throughout an area of shallow ground water. On the other hand, the water table generally is mounded where streams, lakes, canals, or reservoirs are losing water to the ground-water reservoir. A thinner section or less permeable material is indicated where the gradient steepens. Where the saturated materials are thin the underlying bedrock floor has considerable influence upon the configuration of the water table, as its shape conforms roughly to the configuration of the relatively impermeable bedrock surface. Many local irregularities in the shape of the water table are too small or short lived to be shown on the water-table contour map.

Although small hills and depressions on the land surface are not reflected in the shape of the water table, the configuration of the water table conforms, in general, to the configuration of the land surface. The overall slope of the water table is, therefore, in a downstream direction. The movement of ground water toward the South Platte River indicates that the river is gaining water from the ground-water reservoir. Ground water also moves in a downstream direction toward Beebe Seep and sustains its flow. Box Elder Creek, however, is a losing stream during flood stages and contributes to the ground-water reservoir. The water-table contours indicate that the creek was dry throughout most of its length at the time the water-level measurements were made.

DEPTH TO WATER

The depth to the unconfined ground water in the main valleys in the report area generally is related to the configuration of the land surface; generally the depth is greater where the land surface is high and least where the land surface is low. The depth to water, which

ranges from 0 to 80 feet, is shown on plate 6. The boundaries of the areas of different depths to water were delineated by superimposing a topographic base map on the map showing the configuration of the water table and connecting the points of equal differences in altitutde where the contour lines crossed.

On the flood plain of the South Platte River, the depth to water is generally less than 10 feet; in many places it is less than 5 feet, and the zone of continuous capillary rise (the capillary fringe) extends either to the land surface or to the root zone of the vegetation. The water table intersects the land surface in some places and forms swampy areas in which the rate of evapotranspiration is high. On the Kuner terrace the depth to water ranges from less than 10 to about 20 feet, and on the Kersey terrace it ranges from about 10 to about 40 feet. In areas immediately upstream from the three reservoirs in Beebe Draw, the depth to water is less than 5 feet; elsewhere in Beebe Draw the depth to water is less than 60 feet. In the Box Elder Creek valley the depth to water is generally less than 40 feet.

Because the water table rises and falls in response to the varying ratio of recharge to discharge, the depth to water is not constant and so may differ from time to time from that shown on plate 6.

FLUCTUATIONS

The ground-water reservoirs in the valleys in the report area have rather definite basal and lateral limits because of the pressure of the relatively impermeable bedrock floor and walls, but they generally have no confining upper boundary. Consequently, any change in the volume of stored water is reflected by a change in the elevation of the water table in much the same manner as the water level in a surface reservoir indicates the amount of water in storage in the reservoir. In a ground-water reservoir, however, the water level may be falling in one locality, whereas it is rising in another; these differences cause mounds and depressions on the water table. Water-level fluctuations indicate the changes in storage that result from recharge to or discharge from the ground-water reservoir during a given period. Because the movement of ground water within the reservoir is slowed by friction in passing through the relatively small openings in the rock and soil material, the fluctuations of the water table are not as sudden as water-level changes in bodies of surface water. However, because only part of the volume of a ground-water reservoir is occupied by water, the magnitude of fluctuation is greater in a ground-water reservoir than in a surface-water reservoir if equal quantities of water are added to or withdrawn from both.

During years of low precipitation and surface-water runoff, pumping of ground water from wells is generally increased and the water

table declines, especially in areas where recharge to the ground-water reservoir is small. Conversely, during periods of high precipitation and abundant recharge to the ground-water reservoir, withdrawal of ground water by pumping is reduced and the water table rises. The decline of the water table during a dry period does not necessarily mean that an excessive amount of ground water has been pumped from wells; instead, the pumped water may, in effect, have been water that otherwise would have been discharged by natural processes. Because natural discharge from an aquifer is continuous, or almost continuous, water levels tend to decline continuously in the absence of recharge. Water levels rise only during the intermittent periods when the rate of recharge exceeds discharge. During a period of several years, if ground water is not being depleted by overpumping, the quantity of discharge is about equal to the quantity of recharge and the water table remains relatively stable.

The locations of 44 observation wells are shown in figure 9 and the fluctuations of water levels in the wells are shown graphically in figures 10–13.

For purposes of comparison with the water-level fluctuations in the wells, graphs of the annual discharge of the South Platte River at three stream-gaging stations and of precipitation at three weather stations are included in the figures.

RECHARGE

PRECIPITATION

Much of the recharge to the ground-water reservoir occurs by direct infiltration of precipitation. Part of the precipitation leaves the area by direct (overland) runoff, part evaporates, and part replaces previously depleted soil moisture and is returned to the atmosphere by plants. The remainder, if any, infiltrates to the water table. The amount of recharge is dependent upon the duration and intensity of the precipitation, the topography, the type of vegetation, the rate of evaporation, the permeability of the soil and rock materials, and vegetal withdrawal of moisture from the soil. Areas where the surficial materials are sandy are excellent for recharge from precipitation.

Data are not adequate to determine the total quantity of water recharged to the ground-water reservoir from precipitation. The amount of recharge, however, can be estimated from records at the three weather stations (fig. 6), which are assumed to be representative for the whole area. The normal annual precipitation is about 13 inches and the total report area is about 970 square miles; thus, the yearly volume of precipitation is approximately 670,000 acre-feet. The part that becomes recharge probably is less than 10 percent of the total, or less than 67,000 acre-feet.

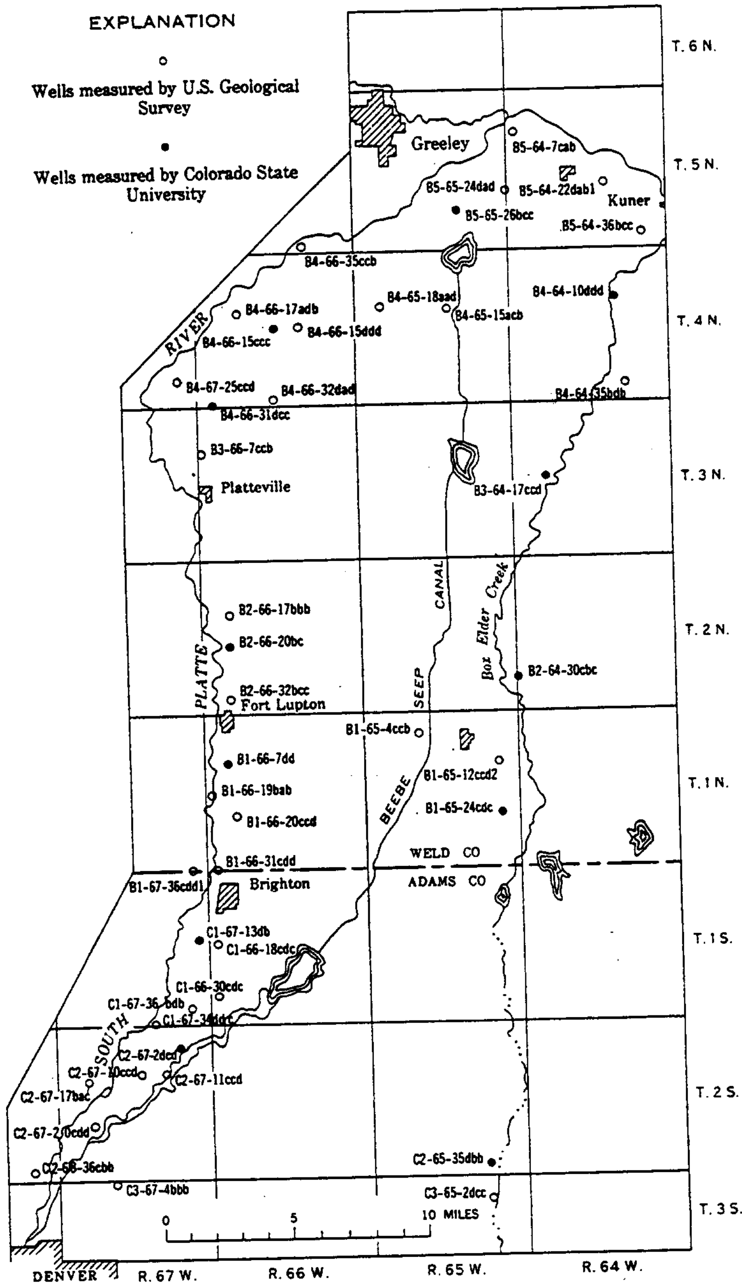

Figure 9.—Map of the South Platte River basin in western Adams and southwestern Weld Counties, Colo., showing the locations of observation wells.

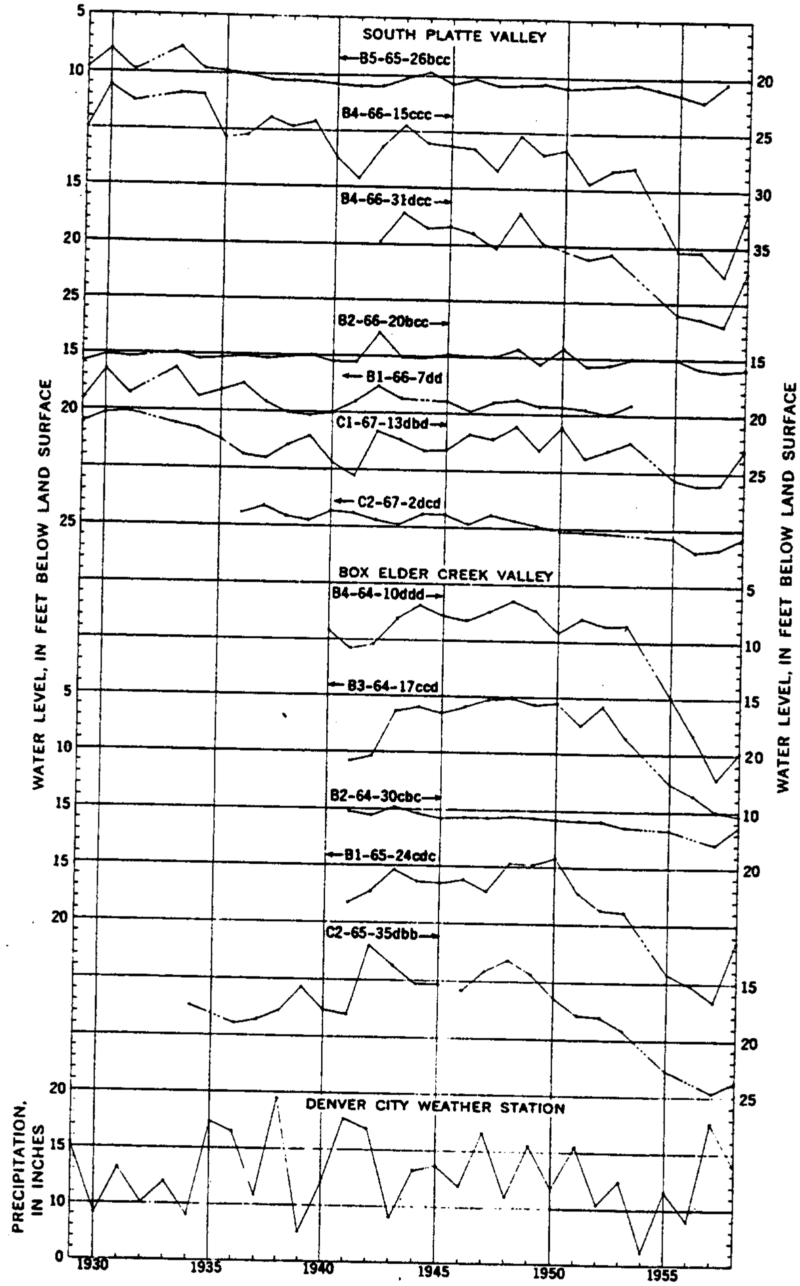

FIGURE 10.—Long-term water-level fluctuations of 12 wells, and precipitation at the Denver city weather station. (Water levels measured by W. E. Code, Colorado State University.)

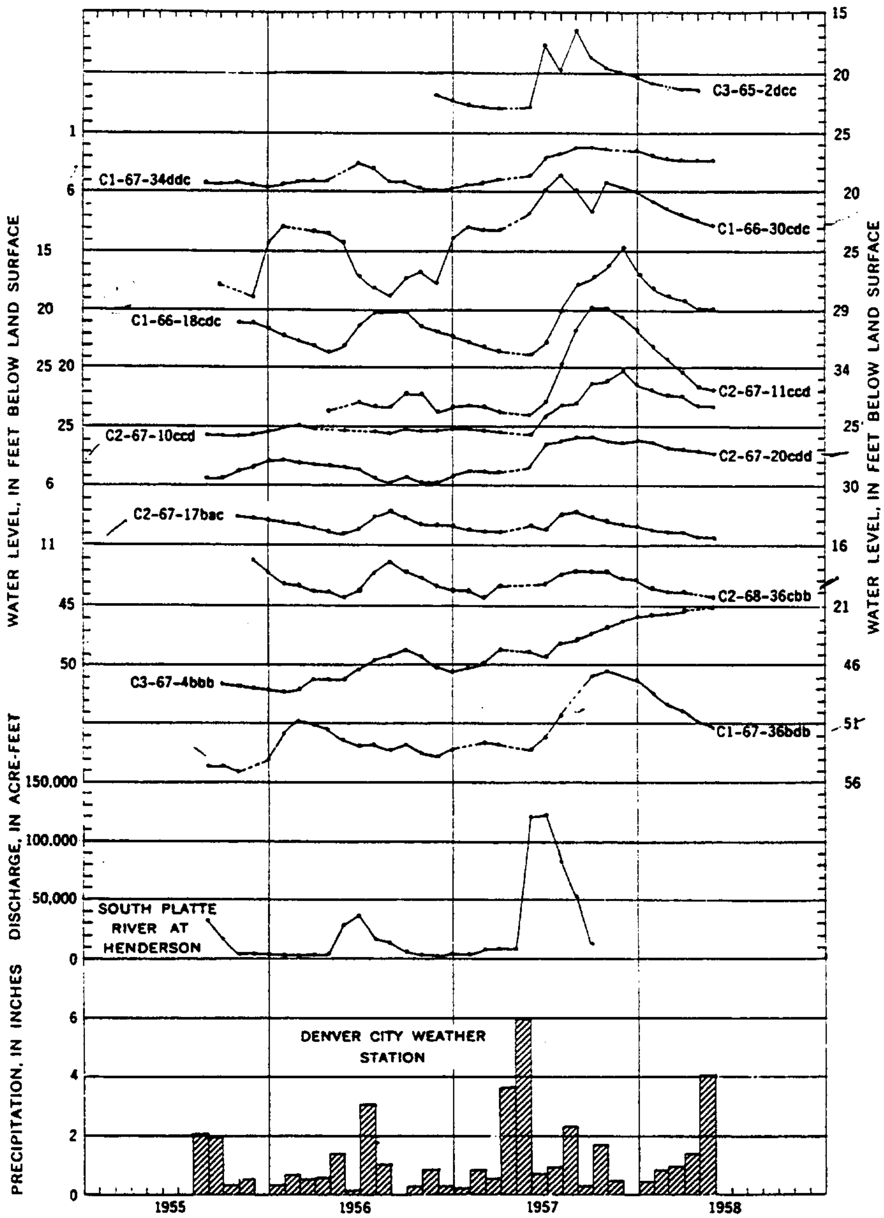

Figure 11.—Short-term water-level fluctuations in 11 wells; discharge of the South Platte River at Henderson; and precipitation at the Denver city weather station.

SEEPAGE FROM IRRIGATED TRACTS, RESERVOIRS, CANALS, AND STREAMS

Both surface water and ground water are used for irrigation in the report area. The surface water is either diverted directly from the streams or released from the storage reservoirs and the ground water is pumped from many wells that tap the valley fill. The locations of nearly all the irrigation wells in the area are shown on plate 7. Most of the irrigated land is underlain by permeable unconsoli-

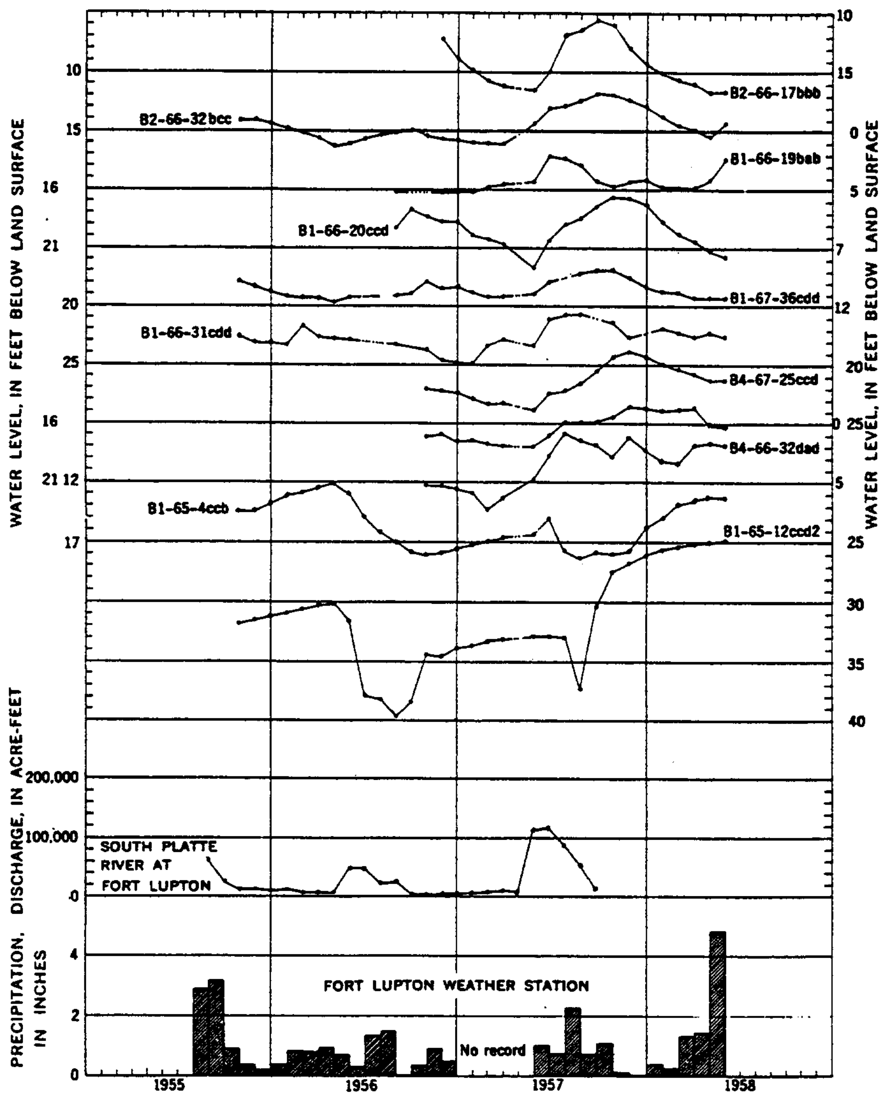

FIGURE 12.—Short-term water-level fluctuations in 11 wells; discharge of the South Platte River at Fort Lupton; and precipitation at Fort Lupton.

dated deposits and a large amount of recharge results from the percolation of water that is spread for irrigation. Evidence of such recharge is apparent from the hydrographs of wells B5–65–24dad (fig. 13) and C1–66–18cdc (fig. 11), which are in the center of a large

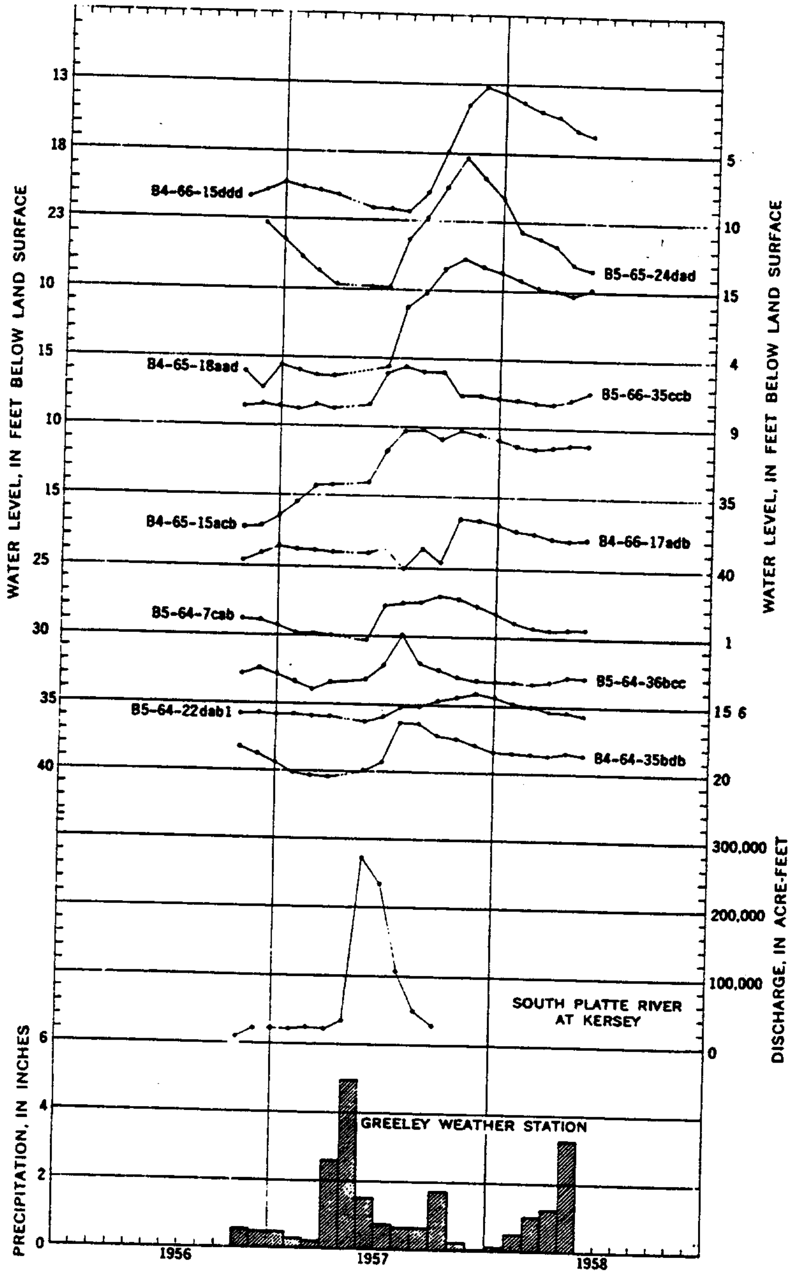

FIGURE 13.—Short-term water-level fluctuations in 10 wells; discharge of the South Platte River at Kersey; and precipitation at Greeley.

irrigated area and not close to a stream. The water level rises sharply in these wells immediately after irrigation starts. Computation of the amount of recharge from irrigation is beyond the scope of this study, but it is estimated that about 40 percent of the water spread for irrigation infiltrates to the ground-water reservoir.

Most of the reservoirs, canals, and laterals in the basin are above the water table and are sources of a large amount of ground-water recharge. Because most of these structures are unlined, seepage from them occurs whenever they contain water. Local authorities estimate that the average loss of water from the main canals and laterals is about 35 percent of the water that is diverted from the river. Part of the loss from the canals and laterals is consumed by evapotranspiration, but this component of the loss is assumed to be small in comparison to the part of the loss due to seepage. Although the seepage losses from the reservoirs have not been estimated, the steepness of the contours on the water table immediately downstream from the reservoirs and the fluctuations of water levels in wells near the reservoirs indicate that the quantity is appreciable.

Intermittent streams, such as First, Second, Third, and Box Elder Creeks, and numerous other small tributaries in the area are above the local water table along most of their courses and, hence, lose water to the ground-water reservoir. For this reason, they are called "influent," or "losing" streams. The permeable beds of these losing streams are dry most of the time, but cloudbursts and prolonged heavy rains have caused them to flood, and much of the floodwater recharges the underlying ground-water reservoir. The amount of recharge depends on the magnitude and duration of the flood, the gradient and permeability of the streambed, and the degree to which the streams meander. In a stream having a relatively straight course and steep gradient the water runs off rapidly, but in a stream having a meandering course the floodwater is impeded and is allowed a greater time in which to infiltrate into the streambed.

The South Platte River is a gaining stream and much of its flow is derived from the ground-water reservoir. In some places, however, where wells near the river are pumped heavily, the direction of ground-water movement may be reversed and recharge from the river temporarily induced.

SUBSURFACE INFLOW

Part of the recharge to the ground-water reservoir in the report area is derived from underflow through the valley fill in the larger valleys, such as those of the South Platte and Cache la Poudre Rivers. Ground water moves into the area through other tributary valleys also; the amount is small however, owing to the relatively low transmissibility and the comparatively small cross-sectional area of the deposits.

Data from the aquifer tests, the water-table contour map, and the geologic cross sections were used to estimate the yearly amount of underflow through the valley-fill deposits (table 3). The estimates were made by applying a modified form of Darcy's law, which may be written as:

$$Q = P_f IA \text{ (cosine } \alpha)$$

in which—Q = quantity of water passing the valley cross section, in gallons per day

P_f = field coefficient of permeability, in gallons per day per square foot at the prevailing ground-water temperature

I = hydraulic gradient of the water table, in feet per mile

A = cross-sectional area through which the water moves, in mile-feet

and— α = angle between the cross section through which the underflow is being determined and a cross section perpendicular to the main axis of the valley.

For example: acquifer tests in the South Platte River valley near the western part of line A–A' indicate that the field coefficient of permeability of the saturated valley fill is about 5,500 gpd (gallons per day) per mile-foot for each foot per mile of gradient. The downvalley gradient of the water table averages 19 feet per mile in the western part, as shown in table 3, and the cross-sectional area of the saturated part of the valley-fill deposits is about 44 mile-feet. It is not necessary to introduce a value for α here because line A–A' is perpendicular to the trend of the valley. On the basis of these computations, the underflow into the area through the valley-fill deposits in the western part of the South Platte River valley is estimated to be about 4,600,000 gpd, or about 5,200 acre-ft per yr. Although the direction of underflow through the higher terrace deposits in the eastern part of the river valley is to the northwest, the downvalley gradient beneath line A–A' is about 7 ft per mile. Underflow beneath this part of line 1 was estimated in a similar manner to be about 4,400 acre-ft per yr. Thus, the total underflow in the South Platte River valley beneath line A–A' is about 9,600 acre-ft per yr.

The underflow into the report area through the valley-fill deposits in the valleys of the Cache la Poudre River and Box Elder Creek were estimated in the same manner. The yearly underflow beneath line I–I' in the valley of the Cache la Poudre River is about 5,700 acre-ft and beneath line A–A' in Box Elder Creek valley is about 2,100 acre-ft.

Sufficient data are not available to estimate the underflow into the report area through the valleys of the Big Thompson River, St. Vrain Creek, Big and Little Dry Creeks, and the small valleys that enter from the north. The combined yearly subsurface inflow through them, however, probably does not exceed 3,000 acre-ft.

TABLE 3.—*Rate of underflow through the valley-fill deposits*

Line [1]	Valley	Field P_f coefficient of permeability (gpd per sq ft)	I Gradient (feet per mile)	A Area (mile-feet)	α	Cosine α	Underflow			
							Million gallons per day	Cubic feet per second	Acre-feet per day	Acre-feet per year
A-A'	South Platte River valley (west part)	5,500	19	44	0	1	4.6	7	14	5,200
A-A'	South Platte River valley (east part)	2,500	7	220	0	1	3.9	6	12	4,400
B-B'	South Platte River valley	5,500	11	77	0	1	4.7	7	14	5,300
D-D'	do	7,000	10	56	0	1	3.9	6	12	4,400
E-E'	do	6,500	11	74	0	1	5.3	8	16	5,900
F-F'	do	4,300	11	138	0	1	6.5	10	20	7,300
G-G'	do	5,500	7	168	0	1	6.5	10	20	7,300
H-H'	do	4,500	7	230	0	1	7.2	11	22	8,100
I-I'	do	3,400	7	270	0	1	6.4	10	20	7,200
I-I'	Cache La Poudre River valley	5,000	6½	158	0	1	5.1	8	16	5,700
J-J'	South Platte River valley	7,500	6	255	25	.91	10.0	16	32	12,000
D-D'	Beebe Draw	8,000	18	50	25	.91	6.6	10	20	7,400
E-E'	do	8,000	14	37	0	1	4.1	6	12	4,600
F-F'	Beebe Draw and Box Elder Creek valley	2,600	14	121	0	1	4.4	7	14	4,900
H-H'	Beebe Draw	4,500	16	65	0	1	4.7	7	14	5,300
A-A'	Box Elder Creek valley	1,500	28	46	0	1	1.9	3	6	2,100
D-D'	Box Elder Creek and Horse Creek valleys	1,500	20	60	0	1	1.8	3	6	2,000
E-E'	Box Elder Creek valley	2,000	17	47	0	1	1.6	2½	5	1,800
H-H'	do	2,500	20	28	0	1	1.4	2	4	1,600

[1] Letter refers to lines of cross sections on pls. 1-3.

The ground-water reservoir is recharged to some extent by lateral underflow from the sand-dune deposits and soil that mantle the uplands around the boundary of the area. The average saturated thickness of these deposits is small, however, and their total recharge to the area by underflow is small in comparison to underflow from the other sources.

DISCHARGE

EVAPOTRANSPIRATION

Ground water is discharged naturally by evaporation and transpiration. Ground water evaporates directly from the ground-water reservoir where the zone of saturation extends to the floor of the stream valleys especially on the flood plain of the South Platte River and near the surface-water reservoirs in Beebe Draw. If the zone of saturation extends near to but not entirely to the land surface, some water evaporates directly from the capillary fringe, but the transpiration of water from plants probably accounts for most of the ground-water discharge by evapotranspiration. Water may be transpired both by native water-loving plants and by cultivated plants. The depths from which plants will lift ground water differs greatly with the type of plants. Most of the ground-water discharge by transpiration occurs in areas where the depth to water is less than 20 feet. The roots of some plants, however, are long enough to reach the water table at depths of several tens of feet.

This investigation did not include a study of evapotranspiration (consumptive use); nevertheless, the evapotranspiration in part of the project area was estimated from data collected during this study together with evapotranspiration data compiled in similar areas. Lowry and Johnson (1942, p. 1243–1266) computed the consumptive use for the stream-valley lowlands in the Garland Division of the Shoshone project, Wyoming; the North Platte River valley, Wyoming and Nebraska; the Mason Creek area of the Boise project, Idaho; and the Uncompahgre Valley, Colo. The climate, length of growing season, irrigation practices, types of crops, and types of soils in the four areas are similar to those in this report area; therefore, the annual consumptive-use values for the four areas were averaged, and the result, 2.11 acre-ft-per acre per yr (rounded to 2 acre-ft per acre), was assumed to be reasonable for the area described in this report. Lowry and Johnson did not compute consumptive use for the nonirrigated uplands in their areas. They computed consumptive use only for the stream-valley lowlands, which included swampland, irrigated land, and areas of natural vegetation adjacent to irrigated areas. In this report area, the boundaries of the stream-valley lowlands were assumed to coincide approximately with the valley-fill

deposits; the area was determined by planimetering the contact between the valley-fill deposits and the bedrock on the geologic map (pl. 1). The nonirrigated uplands, the areas of dune sand, and a nonirrigated area immediately east of Derby were excluded from the computations because sufficient data were not available. The lowland area was determined to be about 220,000 acres and, on the basis of a consumptive-use rate of 2 acre-ft per acre per yr, the total annual discharge of water by evapotranspiration was estimated to be about 440,000 acre-ft. Of this amount an estimated 50,000 acre-ft is direct withdrawal from the ground-water reservoir beneath the flood plain. The 440,000 acre-ft is necessarily a rough estimate because the actual consumptive-use rate may vary widely from the assumed rate used here and because the acreage used is an approximation.

STREAMS, SPRINGS, AND SEEPS

The flow of the South Platte River and Beebe Seep consists partly of ground water discharged directly into the stream channels; the water-table contours indicate that both are gaining streams along most of their course. Some ground water is discharged into drains, which have been constructed on the floor of Beebe Draw and on the flood plain of the river; and the flow from these drains contributes to the streamflow.

Numerous springs and seeps issue from near the toe of the terraces that border the flood plain of the South Platte River, and some of the water flows into the channel of the river or into irrigation canals. Most of the springs issue at the top of beds of clay within the valley-fill deposits.

SUBSURFACE OUTFLOW

A considerable quantity of ground water moves out of the report area through the valley-fill deposits in the valleys that cross the eastern boundary of the area. In order to estimate the amount of underflow in the South Platte River valley, Darcy's law was again applied to the data in table 3. On the basis of these data about 12,000 acre-ft of ground water is estimated to leave the area yearly by underflow through the valley fill. Underflow through the valley-fill deposits in the Box Elder Creek valley beneath the test-hole line *H–H′* was estimated to be about 1,600 acre-ft yearly. The gain to and loss from the ground-water reservoir between test-hole line *H–H′* and the eastern boundary of the report area are believed to be about equal. An undetermined quantity of ground water leaves the area by underflow in the valley immediately below Prospect Reservoir. A detailed local investigation would be required to determine the exact amount, but it probably is small.

WELLS

As of 1958 there were approximately 1,700 irrigation, municipal, and industrial wells of large capacity in the report area, most of which were in the stream valleys. More water is pumped for irrigation use than for all other uses combined. Domestic and stock wells are distributed over both the upland areas and the stream-valley lands. The total withdrawal of ground water from the valley-fill deposits through these small-capacity wells is small compared to that from the large-capacity wells. As shown in tables 4 and 7, pumpage from wells is a large component of ground-water discharge.

TYPES OF WELLS

Most of the irrigation, municipal, and industrial wells that tap the valley-fill deposits are either drilled wells cased with perforated metal (iron or steel) casing that ranges in diameter from 10 to 48 inches, or dug wells lined with perforated concrete casing that ranges in diameter from 2 to 4 feet. The casing in most of the metal-cased wells is either 18 or 24 inches in diameter. A few of the old wells have metal casing 48 inches in diameter, but it is not known whether they were drilled or dug. Most of the dug wells have a concrete casing either 3 or 4 feet in diameter. Some of the old dug wells near Brighton and Fort Lupton have a concrete casing that is 10 feet in diameter at the surface. Below the bottom of the large hole one or more holes of smaller diameter extend deeper. The deeper holes are cased with perforated metal or concrete casing. A few of the dug wells are cribbed with brick, tile, or wood. The domestic and stock wells are of a variety of types. They include the types just mentioned as well as driven, augered, and jetted wells; most are lined with metal casing having a diameter of 8 inches or less. Many are drilled into bedrock aquifers.

METHODS OF DRILLING

Many of the small-diameter wells and most of the deep wells in the area have been drilled by the standard hydraulic-rotary method; the holes generally range from about 4 to 8 inches in diameter. This method is fundamentally the same as that used to drill oil wells, but the drilling rigs used to drill water wells are much smaller than those used to drill oil wells. Drilling is done by rotating the string of drilling pipe to which is attached a rock bit. As drilling progresses, drilling fluid consisting of a mixture of water and mud, clay, or some manufactured product is pumped downward through the rotating drill stem out through the bit, and up the hole to the land surface where it is channeled into a sump pit. The drilling fluid then is taken from the pit by the pump and recirculated in the hole. This very viscous fluid not only lifts the drill cuttings to the surface but also seals

the walls of the hole, thus preventing caving and the loss of fluid pressure by seepage into permeable materials. Holes can be drilled to great depths by the standard hydraulic-rotary method; the maximum depth of water wells drilled by this method in the report area is about 2,000 feet.

Many of the large-diameter wells have been drilled by a relatively new method—the reverse-rotary method. The name "reverse rotary" is derived from the fact that the direction of flow of the drilling fluid is reversed from that of the standard hydraulic-rotary method. During a reverse-rotary operation, a slowly rotating bit at the lower end of a drill stem cuts material loose from the bottom of the hole. The drill hole is kept constantly full of water so that the hydrostatic pressure prevents caving. The water and drill cuttings are pumped up the hollow drill steam and discharged into a settling pit. The drill cuttings remain in the pit but the water overflow runs back into the drill hole by gravity. Generally, a hole drilled by this method is 24–60 inches in diameter. When the desired depth has been reached, a perforated casing of smaller size is placed in the hole and the annular space around the casing is packed with sorted gravel. The reverse-rotary method is very successful for drilling wells in unconsolidated deposits and in some consolidated sedimentary rocks. Two wells in the Denver area were drilled by this method to a depth of about 800 feet in consolidated sedimentary rocks.

The orange-peel bucket has been used to dig many of the large-diameter wells in the report area, especially in the southern part of the South Platte River valley. The heavy metal bucket used in excavating the hole is fitted with four steel jaws, or leaves, which open outward from its bottom; hence, the name "orange peel." The bucket is suspended from a swinging boom by a system of cables, and with the jaws open, it is dropped into the hole. The weight of the bucket digs the jaws into the material at the bottom of the hole. The jaws then are closed on a load of the material, the bucket is withdrawn, and the material is dumped beside the hole. As the digging proceeds, sections of concrete casing, which generally are either 3 or 4 feet in diameter and as much as 4 feet long, are installed in the hole. One end of each section of casing is recessed so that the sections fit snugly together; the weight of the concrete, or of added sandbags, forces the string of casing into the hole. Most wells dug by the orange-peel bucket are not gravel packed. Because the bucket will not penetrate consolidated rock, this method is limited to digging wells in unconsolidated materials.

In the cable-tool method of drilling (sometimes called the "percussion" or "churn-drill" method), a string of heavy drilling tools with a cutting bit at the bottom end is suspended on the end of a

cable from a derrick; the string of tools is lifted and dropped regularly to produce a cutting or drilling action at the bottom of the hole. The drill cuttings are removed from the bottom of the hole by means of a bailer or sand bucket. Usually a metal casing is driven into the hole as the drilling proceeds, and the drilling tools and bailer are lowered and withdrawn through the casing. In some instances, however, when it is desirable to gravel pack a well, a temporary metal casing of large diameter is forced into the hole; then, when the drilling is complete, a perforated casing 18 or 24 inches in diameter is placed within the temporary casing, the annular space between the casings is packed with sorted gravel, and the temporary casing is removed. Both unconsolidated and consolidated rock can be drilled by the cable-tool method.

METHODS OF CONSTRUCTION AND DEVELOPMENT

The most permeable water-bearing zones in the alluvium generally are located by drilling test holes of small diameter with a standard hydraulic-rotary drilling rig, a cable-tool rig, or a power auger. Test drilling is especially advisable when wells of large capacity are desired or when a well is to be drilled in a place where subsurface information is not available.

Wells tapping unconsolidated material are cased the full length of the hole to prevent caving. Generally the casing is perforated, but in some of the older wells of large diameter, the casing is not perforated and water can enter the well only through the open end of the casing.

Most of the recently drilled irrigation, municipal, and industrial wells have been gravel packed. A large hole (24–60 in. in diam.) is put down through the water-bearing formation, then a perforated metal casing or a well screen (generally 18 or 24 in. in diam.) is placed in the center of the large hole, and the annular space around the casing or screen is packed with clean gravel of uniform grain size. Sometimes a string of concrete casing, generally 36 or 48 inches in diameter, is installed in the hole and gravel packed. The perforations in a metal casing are punched or torch-cut slots, whereas those in a concrete casing generally are rectangular openings. Well screens generally have rectangular openings. The size of the casing perforations or of the well-screen apertures is an important factor in the construction of wells, especially large-capacity wells. The openings should be slightly smaller than the grain size of the gravel pack, and the grain size of the gravel pack should be slightly larger than the grain size of the water-bearing material. Care should be taken not to gravel pack a well with material that is less permeable than the water-bearing material.

Some wells are not gravel packed and the perforated parts of the casing are placed below the water table at positions that correspond to the more permeable zones in the water-bearing formation; blank casing generally is placed opposite zones of clay, silt, or fine sand. If a perforation size that will pass the finer grained part of the water-bearing material is selected, a natural gravel packing of the coarser part of the materials is formed around the perforated casing during development of the well. If the perforations are too small, they may become clogged by fine grains or by minerals precipitated from the water.

A well in unconsolidated material should be developed upon completion; that is, the fine-grained material should be removed from the aquifer around the well by pumping or surging and from the bottom of the well by bailing. Removal of the fine-grained material not only will greatly increase the effective diameter of the well and, hence, its yield but also will extend the life of the well. Furthermore, if most of the fine material is not removed during development, it may continue to be pumped from the well and may cause undue wear of the pump. Wells may be developed by installing a turbine pump and pumping the well at alternating high and low rates until the water being discharged contains no sediment. Some wells are developed by plunging a close-fitting surge plate up and down in the casing below the water table; the sediment that accumulates in the bottom of the well then is bailed out.

Wells tapping aquifers in the consolidated rocks are completed by several methods. Some wells, especially the older ones, are cased only in those parts where caving is likely, where prevention of leakage from one artesian aquifer to another is desired, or where the entry of chemically poor water should be prevented. In recent years, however, it has been common practice to case the entire hole and to place perforated casing or well screen opposite only the zones that will yield water of acceptable quality. Many of the wells recently drilled into bedrock aquifers are gravel packed. Most are developed as soon as the casing and gravel pack have been installed, especially if a quantity of water sufficient for municipal or industrial use is desired.

PUMPS AND POWER

Most large-capacity wells in the area are equipped with turbine pumps; a few older ones are equipped with centrifugal suction pumps. Because its impellers are submerged below the depth of maximum drawdown, a turbine pump does not require priming before operation. Power is transmitted directly to the impellers by a vertical shaft within the water-column pipe of the pump. When the shaft and impellers are rotated by an electric motor, a gear head, or a pulley at the top of the pump, water is forced directly up the pump column and out the dis-

charge pipe. The turbine pumps are lubricated either by oil or by water, and the diameter of the discharge pipe ranges from 4 to 12 inches; most of those in the report area are 6, 8, or 10 inches in diameter.

Centrifugal pumps of two types, the horizontal-shaft type and the vertical-shaft type, are used in some of the older large-capacity wells. The horizontal-shaft type is mounted above the water table, some in a pit or in the casing and some at the top of the casing. Vertical-shaft centrifugal pumps are submerged below the depth of maximum drawdown. Power is transmitted to the impellers in both types by a system of shafts and pulleys. Water is sucked into the pumps through an intake suction pipe and pumped out through a discharge pipe. The horizontal-shaft type generally requires priming before operation and will fail to pump water if the drawdown exceeds the suction lift of the pump. The discharge opening of nearly all these pumps generally is 4–12 inches in diameter.

About 95 percent of the pumps in large-capacity wells are driven by electric motors and the remainder are driven by internal-combustion engines that use diesel oil, gasoline, or bottled gas for fuel. Most power units for pumps are stationary, but farm-tractor engines are used to operate a few pumps. Electric power is supplied by the Union Rural Electric Assoc., the Public Service Co. of Colorado, the Colorado Central Power Co., and the Home Light and Power Co. In areas where the pumping lift is less than 20 feet, motors of 7½-, 10- or 15-horsepower generally are sufficient, but where the pumping lift ranges from 20 to 80 feet, 15- to 25-horsepower motors are required. The horsepower of the electric motors averages 12½. Sprinkler irrigation systems generally require about twice as much power as is needed for gravity systems.

The small-capacity wells in the area are equipped with lift (or cylinder), jet, small turbine, submersible, or centrifugal pumps. The lift pumps are operated principally by windmills and the others largely by electric motors; a few pumps are operated by internal-combustion engines or by hand. Most electrically powered domestic units are equipped with pumps that force the water into pressure systems.

YIELDS

The yields of nearly all the irrigation wells in the area were measured with a Hoff current meter, a Parshall flume, or a pitot tube. Because most of the municipal and industrial pumping units are sealed systems, the discharge could be measured in only the few units having flow meters in the discharge system. The discharge of large-capacity wells was determined principally with a Hoff current meter, which was used to measure the velocity of flow in the discharge

pipe of the pump (fig. 14) or in a concrete-lined ditch. The number of revolutions of the current-meter propeller was timed with a stopwatch and the rate of discharge was computed by applying the basic formula (Rohwer, 1942, p. 9):

$$Q=(419\ A-5)\ V$$

in which—Q = discharge of the pump, in gallons per minute

A = cross-sectional area of the discharge opening, in square feet

V = average integrated velocity of the discharging water, in feet per second.

This formula was modified for each individual current meter by a rating factor that was determined each time the meter was rated.

The discharge of some wells could not be measured with a Hoff current meter because the water surged badly or the discharge pipe was obstructed by an alfalfa valve or a metal plate; instead, the discharge was measured by placing a Parshall flume in a ditch in such a way that all the water ran through it. By measuring the height of the water in a flume, the rate of discharge may be read from a standard table. In sprinkler irrigation systems, the rate of discharge was measured by inserting a pitot tube and pressure gage into equally spaced sprinkler heads. The pressure in each sprinkler head can be converted to gallons per minute by the use of standard tables in the manufacturer's handbook, and the total yield of the pumping unit can be determined by averaging the discharge rates and multiplying this average by the total number of sprinkler heads. The yield of some wells that discharge less than 100 gpm was measured by clocking the interval of time required for the discharging water to fill a container of known capacity.

Measured yields of 886 irrigation wells in the area ranged from 45 to 2,040 gpm and averaged about 700 gpm, and the drawdown of the water level in the wells ranged from about 1 to 50 feet. Because most of the measurements were made about 15 minutes after the pumps were started, the measured yields generally were greater and the measured drawdowns less than the average seasonal yields and drawdowns. Such a short period of pumping does not allow sufficient time for the yield of a well and the drawdown to become stable or nearly to reach equilibrium. In some heavily pumped areas, the progressive decline of the water table during the pumping season causes a reduction in the yield of wells and an increase in the drawdown. Conversely, in areas where recharge from surface-water irrigation causes the water table to rise progressively during the irrigation season, the yield of wells increases and the drawdown is reduced. Most of the measured yields and drawdowns, however, are believed to be within 10 percent of the average seasonal yields and drawdowns.

The specific capacity (the number of gallons per minute discharged for each foot of drawdown) of the 668 irrigation wells for which both yield and drawdown data were obtained ranged from 5 to 295. Differences in the permeability and thickness of the water-bearing formations, in methods of well construction, and in the degree of well development cause the wide differences in specific capacities. A comparison of specific capacities, however, is useful in estimating the relative efficiency of wells and the transmissibility (permeability times thickness) of the producing formations.

FIGURE 14.—Rate of discharge from an irrigation well being measured with a Hoff current meter. Photograph by A. I. Johnson.

The amount of water pumped during 1956 and 1957 was computed from the following formula for each electrically powered irrigation well for which the necessary data were available:

$$A = \frac{HQ}{5{,}430}$$

where—
A = amount of water pumped from well during the year, in acre-feet
H = duration, of pumping, in hours per year
Q = rate of discharge, in gallons per minute.
The duration of pumping during the year (H) was calculated by dividing the total amount of power consumed during the year (determined from power-consumption records supplied by the power companies) by rate of power input to the motors (measured by clocking the electric watt-hour meters with a stopwatch). The rate of discharge (Q) was measured by one of the methods described on page 54. By averaging the total amounts of water pumped from the individual wells and applying that average to the large-capacity wells for which the necessary data were not available, the total quantity of water pumped from all the large-capacity wells could be estimated. An average of about 100 kilowatt hours of energy was required to lift 1 acre-foot of ground water to the land surface.

The acreage irrigated with water from individual wells was reported by the well owners or operators when the wells were inventoried.

TABLE 4.—*Estimated quantity of water pumped from large-capacity irrigation wells and acreage irrigated*

	1956	1957
Approximate number of wells pumped	1, 700	1, 700
Estimated pumpage in area, in acre-feet	250, 000	100, 000
Average pumpage per well, in acre-feet	150	60
Total area irrigated with ground water, in acres	100, 000	100, 000
Estimated pumpage per acre, in acre-feet	2. 5	1. 0

The results of the computations and estimates are given in table 4. The estimates are only approximate, because several factors affect their accuracy: (1) The yield of most of the irrigation wells in the area changes during the pumping season, owing to seasonal fluctuations of the water table (discharge measurements made early and late in the pumping season may differ by as much as 10 percent); (2) the yields of wells, which were measured after only a short period of pumping and before the discharge had become stable, decrease after a longer period of pumping; (3) some values for irrigated acreage may be too large, because for some farms the same acreage may have been reported for each of several wells that discharge into a common irrigation sys-

tem; (4) some well owners may have reported the possible maximum acreage that a well can irrigate rather than the actual acreage that was irrigated; (5) some well owners may have included acreage irrigated by surface water; and (6) the yields of only part of the wells were measured. The total quantity of water pumped in the area also changes considerably from year to year, owing to changes in the amount of precipitation and in the available supply of surface water. Because 1956 was a very dry year and 1957 was an extremely wet one, the average, 175,000 acre-ft, is believed to be about the quantity that is pumped for irrigation, municipal, and industrial use during a normal year.

The total amount of water pumped per year from the small-capacity domestic and stock wells that tap unconsolidated materials is estimated to be not more than 500 acre-ft.

GROUND WATER IN THE STRATIGRAPHIC UNITS

BEDROCK FORMATIONS

The Fox Hills sandstone generally does not yield water in sufficient quantities for irrigation use, but it yields small quantities of water to some of the domestic and stock wells in the area. It also supplies small to moderate quantities of water to community, municipal, and industrial wells in the Denver area. The upper sandstone unit is the principal aquifer; the lower part of the formation is not an important source of water because it has a low permeability. Water enters the formation in the areas of outcrop and from overlying formations in the region between the Rocky Mountain Front Range and the western boundary of the report area. Eastward from this region of recharge, the ground water is confined in the sandstone strata under artesian pressure, which in places is sufficient to cause the water to flow from wells at the land surface. The small-diameter domestic and stock wells tapping the Fox Hills sandstone generally yield only a few gallons per minute, but the larger diameter wells in the Denver area yield as much as 75 gpm. Wells near the area of outcrop of the formation (pl. 1) may obtain water at relatively shallow depths, but the depth of wells increases southward as the thickness of the overlying formations increases. Some wells that tap the formation in the Denver area are as much as 2,000 feet deep.

The Laramie formation supplies small quantities of water to domestic, stock, municipal, and industrial wells throughout the area. Water in sufficient quantities for irrigation use generally is not available in the formation. The principal aquifers are the basal sandstone beds, although lenticular bodies of sandstone in the upper part contain some water. Most of the recharge to the permeable beds occurs by direct penetration of precipitation in the outcrop area west of the

project area, but some recharge occurs throughout the area by the downward percolation of water from overlying formations. The water-bearing beds contain water under artesian pressure where they are confined between relatively impermeable beds. The water generally is not under sufficient pressure in the project area to cause it to flow from wells at the land surface. However, the average yield of wells in the Laramie formation is about 15 gpm, but properly constructed wells that penetrate the basal sandstone beds in the Denver area may yield as much as 50 gpm. The depths of the wells that tap the formation differ widely. Many of the wells are less than 100 feet deep, but in the Denver area some wells that tap the basal sandstone beds are 1,000–1,500 feet deep.

Throughout most of the report area the upper sandstone member of the Fox Hills sandstone and the basal sandstone beds of the Laramie formation may be considered a single water-bearing zone that is confined between relatively impermeable strata. This zone contains the most productive aquifers in the two formations, and some wells that penetrate this zone in the southern part of the report area have a sustained yield of about 75 gpm.

The Arapahoe and Denver formations supply water to domestic, stock, municipal, and industrial wells in the southern part of the project area. Although the yields generally are small, 5–50 gpm, some wells that tap the basal part of the Arapahoe formation in the Denver area yield as much as 150 gpm. Beds of sandstone and conglomerate are the most important aquifers and, locally, the ground water is confined under pressure. Water enters the formations where they crop out, mainly in the area surrounding and within Denver, and from the overlying unconsolidated rock materials. The depths of wells in the two formations range from a few hundred feet to about 700 feet.

The Dawson arkose yields small quantities of water to domestic and stock wells in the extreme southeastern part of the report area and in the area along both sides of the Box Elder Creek valley between test-hole line *A–A′* and Keenesburg, where the formation is intertongued with the Laramie and Arapahoe formations. Wells tapping the formation in these areas generally discharge less than 20 gpm; the maximum depth of the wells is about 500 feet.

UNCONSOLIDATED DEPOSITS

The deposits of sand and gravel that mantle the uplands as a thin veneer, or in scattered patches, generally are topographically high and, therefore, are well drained. Although they are not a known source of water for wells, these deposits are hydrologically important because they absorb and transmit precipitation to underlying formations.

The deposits that underlie the older partly dissected terrace in the South Platte River valley between the southern boundary of the report area and Brighton are the source of water for domestic, stock, and irrigation wells. The irrigation wells on the older terrace generally have only moderate yields because the deposits that underlie the terrace contain many zones of relatively low permeability.

The valley-fill deposits that underlie the Kersey and Kuner terraces and the flood plain in the South Platte River valley and that underlie the valley floors of Beebe Draw and the Box Elder Creek valley are the most widely developed and important source of ground water for wells in the report area. The geologic map (pl. 1), the geologic cross sections (pls. 2 and 3), and the map of saturated thickness (pl. 8) indicate the large volume of these unconsolidated materials. Because they are highly permeable, these deposits yield water to wells of all types, many of which are used for irrigation. They are recharged freely by infiltrating precipitation, seepage from surface water (streams, canals, and irrigated tracts), and by underflow from outside the area. They form an almost continuous aquifer in the main valleys and their thickness and permeability generally are sufficient to permit the development of large supplies of water. However, the differences in thickness, permeability, well construction, volume of pumpage, and spacing of wells cause the yields from wells to range from moderate to large. Ground water in the deposits is unconfined, except in some places where relatively impermeable beds locally confine small bodies of ground water under pressure.

The deposits of slope wash that fringe the main valleys are relatively unimportant as aquifers in the report area. They, or interbedded deposits of valley fill, yield water to domestic and stock wells and, in a few places, to small-capacity irrigation wells.

Most of the dune-sand deposits in the area are above the water table and, hence, are not a source of water for wells. They are an ideal medium of recharge to the underlying formations, however, because the sand absorbs precipitation rapidly and allows little or no runoff. Locally, shallow domestic and stock wells may obtain small quantities of water from bodies that are held up in the dune sand by relatively impermeable materials below.

HYDROLOGIC PROPERTIES OF WATER-BEARING MATERIALS

By E. D. Jenkins and W. W. Wilson

The capacity of a rock to yield water to wells and to transmit water under pressure is called permeability. The field coefficient of permeability of a water-bearing material (P_f) is expressed as the number of gallons of water that will percolate in 1 day, at the prevailing

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water temperature, through a vertical section of that material 1 ft high and 1 mile wide for each foot per mile of hydraulic gradient.

The capacity of an aquifer as a whole to transmit water is called transmissibility. The coefficient of transmissibility of a water-bearing material is expressed as the number of gallons of water that will percolate in 1 day, at the prevailing water temperature through a 1-mile-wide vertical section of the full saturated thickness of that material for each foot per mile of hydraulic gradient. Hence, the coefficient of transmissibility is the field coefficient of permeability, as defined above, multiplied by the saturated thickness of the aquifer, in feet.

Part of the water in any deposit will not drain into a well by gravity because it is held against the force of gravity by molecular attraction—that is, by the cohesion of the molecules of water and by their adhesion to the walls of the pores. The ratio of the volume of water that a rock will yield by gravity, after being saturated, to its own volume is known as the specific yield of the rock and is generally expressed as a percentage. The ratio of the volume of water that a rock will retain against the force of gravity, after being saturated, to its own volume is known as the specific retention. The specific yield plus the specific retention equals the porosity of the rock. Thus, if 100 cubic feet of a saturated formation will yield 20 cubic feet of water and retain 15 cubic feet of water, when drained by gravity, the specific yield is 0.20, or 20 percent; the specific retention is 0.15, or 15 percent; and the porosity is 0.35, or 35 percent.

The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface is called the coefficient of storage. If the aquifer is unconfined, the water released from or taken into storage in response to a change in head is due partly to gravity drainage or to refilling of the zone through which the water table falls or rises, and partly to compressibility of the water and aquifer material in the saturated zone. As the volume of water attributable to compressibility generally is a negligible part of the total volume, the storage coefficient of an unconfined aquifer is, for practical purposes equal to the specific yield. If the aquifer is confined, the water released from or taken into storage in response to a change in heads is due solely to compressibility of the aquifer material and of the water. The coefficient of storage of a confined aquifer is, therefore, exceedingly small in comparison to the specific yield of an unconfined aquifer having the same coefficient of transmissibility, generally 0.00001–0.001 for a confined aquifer as compared with a range from a percent or two to 30 percent or more for an unconfined aquifer.

BEHAVIOR OF GROUND WATER IN THE VICINITY OF DISCHARGING WELLS

The following discussion of the behavior of ground water in the vicinity of discharging wells has been adapted largely from Wenzel (1942, p. 98–101), and the reader is referred to his report for a more detailed discussion of the subject.

As soon as a pump begins discharging water from a well that penetrates a water-bearing formation under water-table conditions, a hydraulic gradient is established from all directions toward the well and the water table is lowered around the well (fig. 15). The water

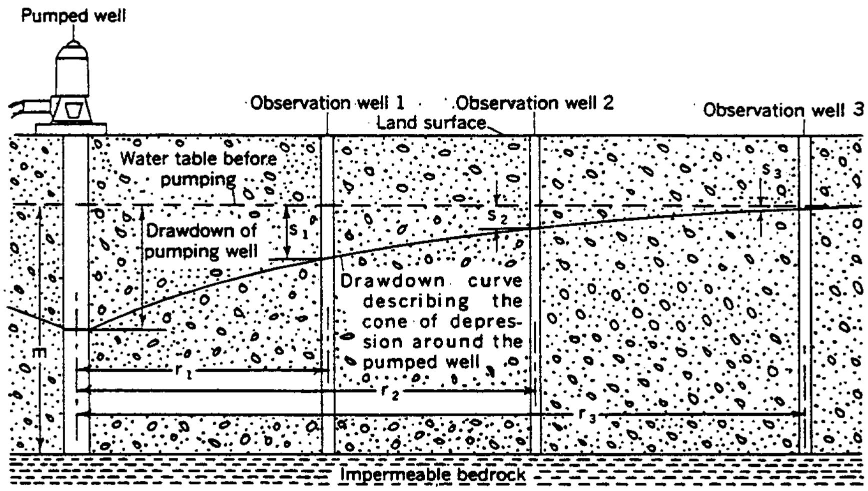

FIGURE 15.—Profile of the water table near a discharging well.

table soon assumes a form comparable to an inverted cone, although it is not a true cone. Where the water-bearing material is homogeneous, this cone of depression will be circular if the initial or static water table is horizontal, but somewhat elliptical if the initial water table is sloping. Some water-bearing material will be unwatered by the decline of the water table, and the water drained from this material will percolate to the pumped well. Thus, for a short time after pumping begins, most of the water that is pumped from a well comes from the unwatered rocks comparatively close to the pumped well and, temporarily, very little water may be drawn toward the well from greater distances. As pumping continues, however, a hydraulic gradient that is virtually an equilibrium gradient is established close to the pumped well, and water is transmitted to the well through the water-bearing material in approximately the amount that is being pumped. The decline of the water table and, hence, the unwatering of material in the cone of depression will then be much slower, with the result that more water percolates toward the well from greater dis-

tances, the cone of depression expands, and water-bearing materials are drained at increasing distances from the pumped well. Thus, as pumping continues, more of the formation will gradually be unwatered, an equilibrim gradient that will transmit to the well approximately the amount of water that is being pumped will be established at increasing distances from the well, and an appreciable drawdown of the water table will be noted at ever-increasing distances from the well. Inasmuch as an equilibrium gradient can be established at increasing distances from the pumped well only by steepening the hydraulic gradient, which in turn can be created only by an increase in drawdown, the water table near the pumped well, in order to maintain an approximate equilibrium form, will continue to lower indefinitely but at a decreasing rate. Recharge to the formation may, however, halt the development of the cone of depression by furnishing additional water, which becomes an additional supply for the pumped well. If no water is added to the formation, the water table will continue to decline as long as the well is pumped, and eventually the cone of depression will extend to the limits of the formation or, if the aquifer is sloping, the downgradient side of the cone will continue to migrate in a downgradient direction as long as pumping continues.

When a well is pumped, the distance to the point where the drawdown is imperceptible is called the radius of influence and the circular or elliptical area described by this radius is called the area of influence of the well. The radius of influence around a discharging well is a function of time, permeability, coefficient of storage, and yield. Where wells are spaced too closely, the cones of depression around the wells overlap (interfere) and, as a result, yields are decreased and pumping lifts are increased. The amount of interference depends upon the distance between wells, the rate and duration of pumping from the wells, and the hydrologic properties of the aquifer. In the vicinity of a discharging well, the drawdown increases with an increase in the rate and duration of pumping and decreases with an increase in distance from the well. Many of the large-capacity wells in the report area are very closely spaced (pl. 7). Mutual interference becomes so critical in some areas, especially during periods of drought and heavy pumping, that the water level is drawn to the bottom of the pump column. Then, either pumping must be temporarily discontinued or the pumping rate must be reduced.

The piezometric surface of an artesian aquifer responds to the pumping of a well in much the same way as does the water table of a nonartesian aquifer; however, the release of water from storage in response to a change in head is due solely to compaction of the aquifer and expansion of the water upon release of pressure. The quantity of water removed from an artesian aquifer by these processes gen-

erally is much less than that removed by dewatering part of a formation under water-table conditions, and the drawdown of the piezometric surface and development of the cone of depression under artesian conditions are much more rapid than under water-table conditions. Therefore, mutual interference between wells takes place sooner and is more extensive under artesian conditions than under water-table conditions.

During the pumping of a well, the drawdown of the water table or piezometric surface at any point is inversely proportional to the permeability or transmissibility of the water-bearing material; hence, the drawdown generally is small in well-sorted gravel and coarse sand and is much greater for the same pumping rate in less permeable materials such as fine sand, silt, or clay.

After the discharge of a well in an unconfined aquifer is stopped, water momentarily continues to percolate toward the well under the hydraulic gradient set up during the period that the well was discharging, but instead of being discharged by the well, the water refills the well and the interstices of the material that were dewatered. As the formation near a well in an unconfined aquifer is gradually refilled, the hydraulic gradient toward the well is decreased and the recovery becomes progressively slower. At distances comparatively far from the well, the water level may continue to lower for a considerable time after discharge ceases because at those distances water still is being taken from the interstices of the material to supply the water that refills the rocks around the well. In time, there is a general equalization of water levels over the entire region and the water table assumes a form similar to that which it had before pumping began, although it may remain temporarily or permanently somewhat lower, according to recharge conditions.

After the discharge of a well in a confined, or artesian, aquifer is stopped, the water momentarily continues to move toward the well, tends to expand the aquifer and associated beds to about their original capacity, and is slightly compressed by the increased pressure.

AQUIFER TESTS

Methods of determining the transmissibility and storage coefficients of a water-bearing material involve an analysis of the rate of decline in water level of an aquifer as water is removed by pumping or of the rate of rise in water level after pumping has stopped. During an aquifer test, the water level is measured in the pumped well and one or more observation wells before pumping begins and at periodic intervals during the test; for a recovery test, the water level is also measured periodically after the pumping stops until the recovery rate becomes very slow.

Nonequilibrium formulas for determining the coefficients of transmissibility and storage by discharging-well methods assume that the

aquifer test is made under the following conditions (Meinzer and Wenzel, 1942, p. 471):

(1) The water-bearing formation is homogeneous and isotropic, (2) the formation has an indefinite areal extent, (3) the pumped well penetrates the entire thickness of the water-bearing formation, (4) the coefficient of transmissibility is constant at all places and at all times, (5) the pumped well has an infinitesimal diameter, (6) the initial nonpumping piezometric surface (or water table) is horizontal, (7) the impervious bed underlying the water-bearing bed is horizontal, and (8) water is taken from storage instantaneously by the decline in head.

Under these conditions, water percolates toward the pumped well equally from all directions and the same quantity of water percolates toward the well through any series of concentric cylindrical sections around the pumped well. Equilibrium formulas also assume that approximate equilibrium is established with a constant rate of pumping and that very little water is removed from storage close to the well. The degree to which these assumptions are fulfilled differs with each aquifer test and governs the accuracy of coefficients determined by the test.

From data gathered from one observation well during an aquifer test, the coefficients of transmissibility and storage of an aquifer can be computed by the Theis nonequilibrium formula (Theis, 1935, p. 520). In units commonly used by the Geological Survey, this formula is as follows:

$$T=\frac{115Q}{s}W_{(u)} \tag{1}$$

$$u=\frac{1.87r^2S}{Tt} \tag{2}$$

where—

T=coefficient of transmissibility, in gallons per day per foot
Q=discharge of pumped well, in gallons per minute
S=drawdown (or recovery) in observation well, in feet
s=coefficient of storage
r=distance of observation well from pumped well, in feet
t=time since pumping started (or stopped), in days

and—

$W_{(u)}$=the well function of u. $W_{(u)}$ values for corresponding values of u were computed by Kazmann (Wenzel, 1942, p. 88–89).

The modified nonequilibrium formulas described by Jacob (1947) also can be used to determine the coefficient of transmissibility and storage from the data obtained while the well was being pumped or from the recovery data. These formulas, simplified for graphic solution and expressed in units used by the Geological Survey, have the form:

$$T=\frac{264Q}{\Delta s} \tag{3}$$

and—

$$S=\frac{0.3Tt_o}{r^2} \tag{4}$$

in which—

T, Q, s, S, t, and r are as previously defined

and—

t_o = time, in days, at which no drawdown (or recovery) appears to occur

Δs = the drawdown difference per log cycle of t.

The Thiem equilibrium method of determining the coefficients of transmissibility and storage of an aquifer involves the analysis of the decline in water level during the pumping period in two or more observation wells near a well that is being pumped. The derivation of the general Thiem formula was discussed by Wenzel (1942, p. 81), and a graphic method for solving the Thiem formula was described by Jacob (1944). Jacob's modification of the Thiem formulas may be written:

$$\frac{T=528Q}{\Delta s'} \tag{5}$$

and—

$$\frac{S=0.3Tt}{r_e^2} \tag{6}$$

in which—

T, Q, S, r, and t are as previously defined

r_e = maximum extent of cone of depression at time t, in feet

s' = adjusted drawdown of water level in the observation well, in feet, and is equal to

$$s-\frac{s^2}{2m}$$

where—

m = saturated thickness of the aquifer, in feet.

If, for these formulas, t is not sufficiently large, S will be only the apparent coefficient of storage and may be considerably less than the true coefficient of storage.

The apparent coefficient of storage of an unconfined aquifer increases with duration of pumping, rapidly at first and then more and more slowly until the true coefficient of storage is approached. The length of pumping time necessary to obtain a reasonable value for the coefficient of storage is governed by the time required to drain completely the sediments within the cone of depression. Many days or weeks of pumping may be required for fine-grained sediments to become largely drained, whereas only a few hours of pumping may be needed for very coarse-grained sediments. The true coefficient of storage can be estimated from the projection of a curve in which the apparent coefficient of storage has been plotted against time or from the projection of several curves on logarithmic probability paper. In the latter method,

the apparent coefficients of storage divided by an assumed coefficient of storage are plotted against time; from the projection to some later t, the coefficient of storage can be calculated.

The specific capacity of a well is its rate of yield per unit of drawdown and is generally determined by dividing the yield, in gallons per minute, by the drawdown, in feet. It is a function of factors other than transmissibility, including duration of pumping, the diameter of the well, its depth of penetration into the aquifer, the effectiveness of the casing perforations or well screens, the extent and effectiveness of well development, and the distance from nearby wells that are being pumped. Under water-table conditions, the specific capacity of even a fully developed well is nearly constant only when the drawdown is a small fraction of the saturated thickness of the aquifer. Because, in general, high specific capacities indicate that the aquifer has a high transmissibility, and low specific capacities indicate that the aquifer has a low transmissibility, the specific capacity of a well may be considered to be a measure of the magnitude of the transmissibility of the aquifer According to a method developed by Theis and others (1954), as used by Back (1957, p. 4–6, 30–32), an approximate value for transmissibility can be obtained by multiplying the specific capacity in gallons per minute per foot of drawdown by 2,000.

The coefficients of transmissibility and storage of the valley-fill deposits in the valleys of the South Platte River, Beebe Seep, and Box Elder Creek were calculated from data from 41 aquifer tests at the locations shown in figure 16. Nearly all the wells tested during this investigation penetrate the entire aquifer and were constructed with casings that range from 18 to 24 inches in diameter. However, a great variety of casing perforations were used, and the methods and extent of well development differed widely throughout the report area. The equipment used to make the tests included a stopwatch, a Parshall flume, Hoff current meter or other device for measuring well discharge, an electric-contact or steel tape for measuring depth to water, and a barometer for determining changes in atmospheric pressure.

Before an aquifer test was begun, the static (nonpumping) water levels in the test well and in all nearby wells accessible for water-level observation were measured. The test well then was pumped at the most uniform rate possible for a period ranging from several hours to several days, during which time the discharge from the well and the depth to water in the well were measured at periodic intervals. Where nearby observation wells were available, water levels in them also were measured periodically (fig. 15). After pumping was stopped, periodic measurements of the water levels in the pumped and observation wells were continued until the water levels approached their original static position.

The results of the aquifer tests made in the report area are summarized in table 5. The coefficients of transmissibility ranged from

35,000 to 500,000 gpd per ft. Such a wide range is to be expected because the valley-fill deposits range widely in saturated thickness and in the size, shape, and degree of interconnection of interstices.

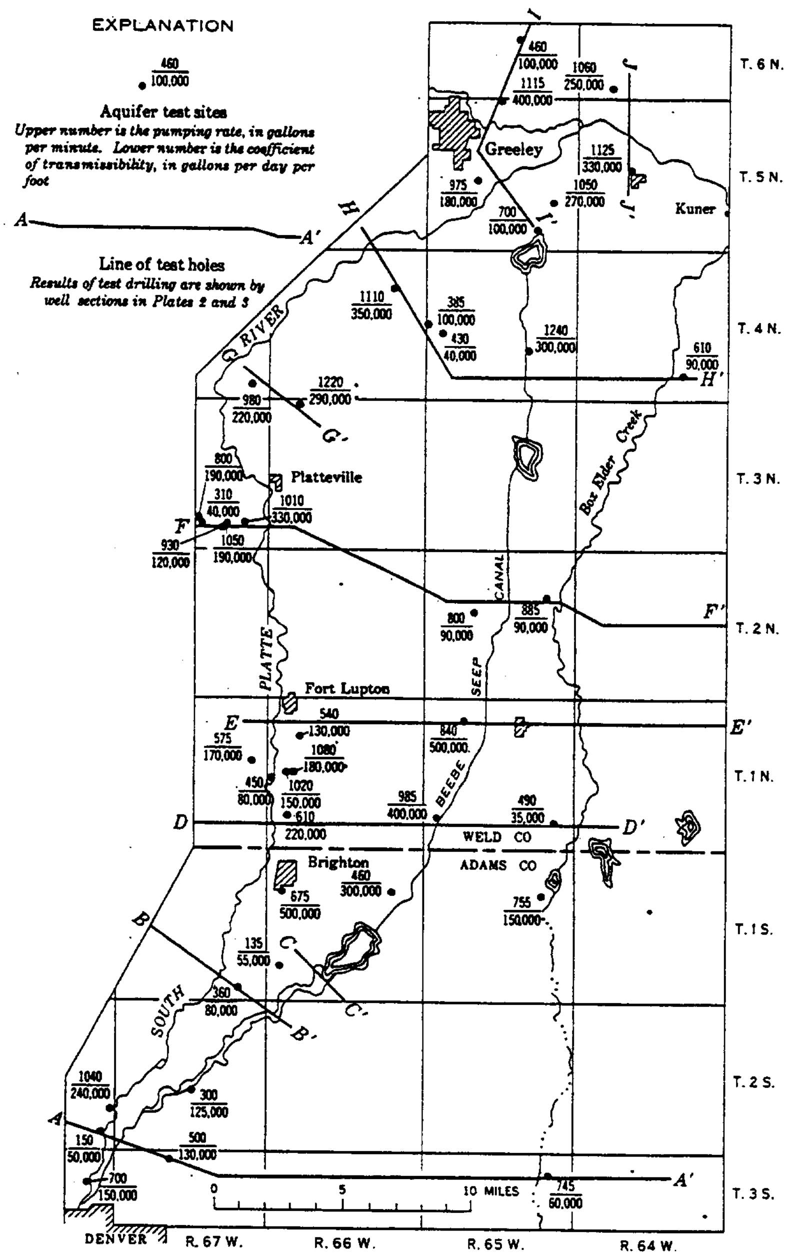

Figure 16.—Map of the South Platte River basin in western Adams and southwestern Weld Counties, Colo., showing the location of aquifer tests, coefficients of transmissibility, pumping rates, and the lines of test drilling.

TABLE 5.—*Summary of the results of aquifer tests*

[Principal water-bearing beds: CL, valley-fill deposits in Cache La Poudre River valley; BE, valley-fill deposits in Box Elder Creek valley; B, valley-fill deposits in Beebe Draw; SP, valley-fill deposits in South Platte River valley]

Well	Owner	Principal water bearing bed	Depth of well (feet)[1]	Depth to—		Total saturated thickness (feet)	Saturated sand and gravel (feet)	Duration of pumping (hours)	Average pumping rate (gpm)	Draw-down (feet)
				Bedrock (feet)	Water below measuring point (feet)					
B1-65-5dcc2	Fred Rupple	B	79	81	45.6	35	29	10	840	4
25ccd2	Fred Haffner	BE	62.6	65	33.2	32	22	5	490	22
30dcb	Gus Henkel	B	55.0	61	15.3	46	27	8	985	14
B1-66-8bcd1	V. and H. Frick	SP	37.5	33	16.4	17	17	28	540	15
18ddc	C. M. Whiteside	SP	51.4		18.9	32		16	1,020	14
18ddd	do	SP	39.6		16.9	23		15	1,080	22
19bbc	Charles Ocker	SP	23.4		7.0	16		7	450	7
30dad	Albert Bucci, Sr	SP	40.3		17.9	22		8	610	12
B1-67-13bdd	Harry Chikuma	SP	38		9.3	29		5	575	8
B2-65-11ddd	Donald Dowdy	BE	53.3		14.4	39		16	885	38
16bcc	H. J. Thomason	B	84.0		53.5	30		14	800	19
B3-66-5bba	L. and D. Koehler	SP	78.0	78	22.3	56		8	1,220	24
B3-67-25ccc	Richard Means	SP	36.2	36	7.8	28	28	9	1,010	7
26cdc	Ivan Morgan	SP	60.8		18.7	42		2	1,050	19
27ccb	J. C. Vollmar	SP	51.0	51	16.5	35	35	5	800	12
27ccd	do	SP	27.7		8.3	19		2	310	16
35bbb	J. W. Weber	SP	78.3	78	33.9	44	27	7	930	19
B4-64-26ccd	Hilding Berg	BE	69		30.7	38		46	610	25
B4-65-18ccc	Jack Noel	SP	55.8		20.1	36		4	385	12
19abd	Warren McMillan	SP	48.0		9.5	39		8	430	31
23ccc	Daniel Bohlender	B	74.0	75	11.2	64	47	10	1,240	11
B4-66-11adc2	Love and Sons	SP	72.2		35.2	37		12	1,110	9
B4-67-36bdc1	C. Hildenbrandt	SP	57.7		21.7	36		12	980	10

B5-64-16ccb2	Frank Bond	SP	81.3		31.7	50		4	1,125	7
B5-65-3bbb	A. H. Purdy	CL	101.5		35.7	66		12	1,115	7
21bbb	C. G. Miller	SP	112		34.5	78		4	975	10
25bbb	Harold L. Johnson	SP	45.0	69	6.9	62		7	1,050	15
35abc	W. J. Trembath	SP	60.4		20.6	40	10	14	700	30
B6-64-32cab	C. S. Moore	SP	58.7	58	27.7	31		15	1,060	9
B6-65-22dba2	Pearl Brooks	CL	64.5		39.2	25		13	460	16
C1-65-11ddb	David Patton	BE	62.8		30.8	32		10	755	16
C1-66-7dbb	City of Brighton	SP	50.1		16.0	34		6	675	2.3
11ddb	Kazumi Furuta	B	55.8		16.3	39		10	460	4
30dbc	J. Knowlton	SP	35.6	42	20.7	15	6	9	135	12
C1-67-35add2	J. H. Imatani	SP	38.7	39	18.9	20	17	10	360	11
C2-67-22bcc1	Harry Nesom	SP	48.4	47	33.0	15	15	27	300	5
C2-68-25add2	Northwest Utilities Co.[3]	SP	30		5.2	25		7	1,040	18
36bda [4]	North Washington Water and Sanitation District.[4]	SP	18	18	6.0	12	12	18	150	11
C3-65-1ccc	Vivian E. Adee	BE	73.8	73	35.5	38	8	38	745	27
C3-67-4bca	Rocky Mountain Arsenal [4]	SP	96	96	50.5	45	28	64	500	8
C3-68-11ada	Public Service Co. of Colorado [4]	SP	30.0	30	7.1	23	22	72	700	12

See footnotes at end of table.

TABLE 5.—*Summary of the results of aquifer tests*—Continued

[Principal water-bearing beds: CL, valley-fill deposits in Cache La Poudre River valley; BE, valley-fill deposits in Box Elder Creek valley; B, valley-fill deposits in Beebe Draw; SP, valley-fill deposits in South Platte River valley]

Well	Owner	Specific capacity (gpm per ft.)	Coefficient of— Transmissibility (in thousands of gpd per ft)	Permeability of entire aquifer (gpd per sq ft)	Permeability of sand and gravel (gpd per sq ft)	Radius of influence at end of test period (feet)	Apparent coefficient of storage	Water temperature (°F.)	Date begun	Method of computation
B1-65-5dcc2	Fred Rupple	210	500	14,000	17,000	700	0.13	55	8-13-57	Jacob, Thiem.
25ccd2	Fred Haffner	22	35	1,100	1,600	500	--------	55	8-14-57	Jacob.
30dcb	Gus Henkel	70	400	8,700	15,000	3,000	.002	64	8-15-57	Jacob, Theis.
B1-66-8bcd1	V. and H. Frick	36	130	7,600	7.600	600	.04	54	9-11-56	Jacob, Theis, Thiem.
18ddc	C. M. Whiteside	73	150	4,700	--------	--------	--------	57	8-15-56	Jacob.
18ddd	do	49	180	7,800	--------	700	.15	58	8-15-56	Jacob, Theis.
19bbc	Charles Ocker	64	80	5,000	--------	800	.06	58	9-5-56	Jacob.
30dad	Albert Bucci, Sr	51	220	10,000	--------	1,000	.09	56	8-14-56	Jacob, Theis.
B1-67-13bdd	Harry Chikuma	72	170	5,800	--------	--------	--------	55	9-6-56	Jacob.
B2-65-11ddd	Donald Dowdy	23	90	2,300	--------	--------	--------	--------	8-7-57	Jacob.
16bcc	H. J. Thomason	42	90	3,000	--------	1,500	.02	55	8-7-57	Jacob, Theis.
B3-66-5bba	L. and D. Koehler	51	290	5,200	--------	--------	--------	54	8-6-57	Jacob.
B3-67-25ccc	Richard Means	144	330	12,000	12,000	--------	--------	60	9-11-56	Jacob.
26cdc	Ivan Morgan	55	190	4,500	--------	--------	--------	--------	8-16-57	Jacob.
27ccb	J. G. Vollmar	67	190	5,400	5,400	--------	--------	--------	8-24-56	Jacob.
27ccd	do	19	40	2,100	--------	--------	--------	--------	8-24-56	Jacob.
35bbb	J. W. Weber	49	120	2,700	4,400	3,000	.003	57	8-22-56	Jacob, Theis.
B4-64-26ccd	Hilding Berg	24	90	2,400	--------	--------	--------	55	7-15-57	Jacob.
B4-65-18ccc	Jack Noel	32	100	2,800	--------	--------	--------	54	7-19-57	Jacob.
19abd	Warren McMillan	14	40	1,000	--------	--------	--------	54	7-12-57	Jacob.
23ccc	Daniel Bohlender	113	300	4,700	6,400	--------	--------	55	9-14-56	Jacob.
B4-66-11adc2	Love and Sons	123	350	9,500	--------	1,000	.03	56	7-11-57	Jacob.
B4-67-36bdc1	O. Hildenbrandt	98	220	6,100	--------	1,000	.02	55	7-30-57	Jacob, Theis.

B5-64-16ccb2	Frank Bond	161	330	6,600				57	7-17-57	Jacob.
B5-65-3bbb	A. H. Purdy	159	400	6,100				54	7-22-57	Jacob.
21bbb	C. G. Miller	97	180	2,300				54	7-25-57	Jacob.
25bbb	Harold L. Johnson	70	270	4,400		500	.15	54	8-9-57	Jacob, Thiem.
35abc	W. J. Trembath	23	100	2,500	10,000	600	.06	56	7-27-57	Jacob.
B6-64-32cab	C. S. Moore	118	[2] 250	[2] 8,000		900	.08	54	7-18-57	Jacob.
B6-65-22dba2	Pearl Brooks	29	100	4,000		1,500	.01	54	7-24-57	Jacob, Thiem.
C1-65-11ddb	David Patton	47	150	4,700				54	8-29-57	Jacob.
C1-66-7dbb	City of Brighton	294	500	15,000					8-11-56	Jacob.
11ddb	Kazumi Furuta	115	300	7,700				52	8-28-57	Jacob.
30dbc	J. Knowlton	11	55	3,700	9,200			54	8-10-56	Jacob.
C1-67-35add2	J. H. Imatani	33	80	4,000	4,700	900	.07	55	8-7-56	Jacob, Thies.
C2-67-22bcc1	Harry Nesom	60	120	8,300	8,300	700	.09	55	11-8-55	Jacob, Thiem.
C2-68-25add2	Northwest Utilities Co.[3]	58	240	9,600		300	.21	54	8-30-54	Theim.
36bda	North Washington Water and Sanitation District.[4]	14	50	4,200	4,200	500	.04	55	6-25-56	Thiem.
C3-65-1ccc	Vivian E. Adee	28	60	1,600	1,600			54	8-17-57	Jacob.
C3-67-4bca	Rocky Mountain Arsenal[5]	63	130	2,900	4,600	1,500	.06	56	7-16-53	Jacob, Thiem.
C3-68-11ada	Public Service Co. of Colorado[6]	58	150	6,500	6,800	900	.16	52	6-6-55	Jacob, Theis, Thiem.

[1] Measured depths are given in feet and tenths below measuring point; reported depths are given in feet below land-surface datum.
[2] Average.
[3] Data from Northwest Utilities Co., Thornton, Colo.
[4] Data from North Washington Water and Sanitation District, Welby, Colo.
[5] Data from Corps of Engineers, U.S. Army, Omahoa district, Omaha, Nebr.
[6] Data from Ebasco Services, Inc., Denver, Colo.

The field coefficients of permeability of the saturated valley-fill deposits ranged from 1,000 to 15,000 gpd per sq. ft. as determined from 41 aquifer tests, and the permeability of the beds of sand and gravel alone ranged from 1,600 to 17,000 gpd per sq. ft. as determined from 16 aquifer tests.

The coefficient of storage of the valley-fill deposits, as determined in about 20 of the tests, ranged from 0.002 to 0.21; in only a few tests did it exceed 0.15. The values are believed, for the following reasons, to be conservative: (1) The water is semiconfined in some areas where the water-bearing beds are intercalated with extensive layers of comparatively low permeability; because some tests in these areas were not long enough for the water level to decline below the confining layer, the values obtained represent the storage coefficient of the semiconfined, rather than the unconfined, aquifer; (2) because of a variety of physical limitations, it commonly was not possible to pump the wells long enough to allow the cone of depression to become largely drained; the coefficient of storage determined in such short-duration tests generally ranged from only 0.02 to about 0.10; (3) although many wells were pumped long enough to permit adequate drainage of the coarse water-bearing materials, it was not possible to avoid the local effects of irrigation; some of the water pumped onto the ground and distributed to the fields probably returned to the ground-water reservoir during the test and tended to refill the cone of depression before it was adequately drained. The tests of wells C3–68–11ada and C2–68–25add2 appear to be the only ones that were of the proper order of magnitude and that were sufficiently free of other disturbing effects to be considered reliable for the determination of the coefficient of storage of the valley-fill deposits. The results of these tests indicate a coefficient of storage of not less than 0.20.

As shown in figure 17, the apparent coefficient of storage of the sediments near well C3–68–11ada increased from about 0.05 after 5 hours of pumping to 0.16 after 3 days of pumping. By projecting the curve, it appears that the value for the coefficient of storage after 10 days of pumping may exceed 0.22. The apparent coefficient of storage determined by the test of well C2–68–25add2, which penetrates very coarse grained materials, was computed for various times and was plotted on logarithmic probability paper as shown in figure 18. A probable value of 0.40 for the coefficient of storage was used to construct line A, a probable value of 0.30 for line B, and 0.25 for line C. If each line is extended until it intersects a time of 100 hours, line A reaches a value of 0.61 of the probable value of 0.40, or a coefficient of storage of 0.24; line B reaches 0.82 of its probable value of 0.30, or 0.25; and line C reaches 0.96 of its probable value of 0.25, or 0.24. All three of these curves approach a value of about 0.24 where t is 100

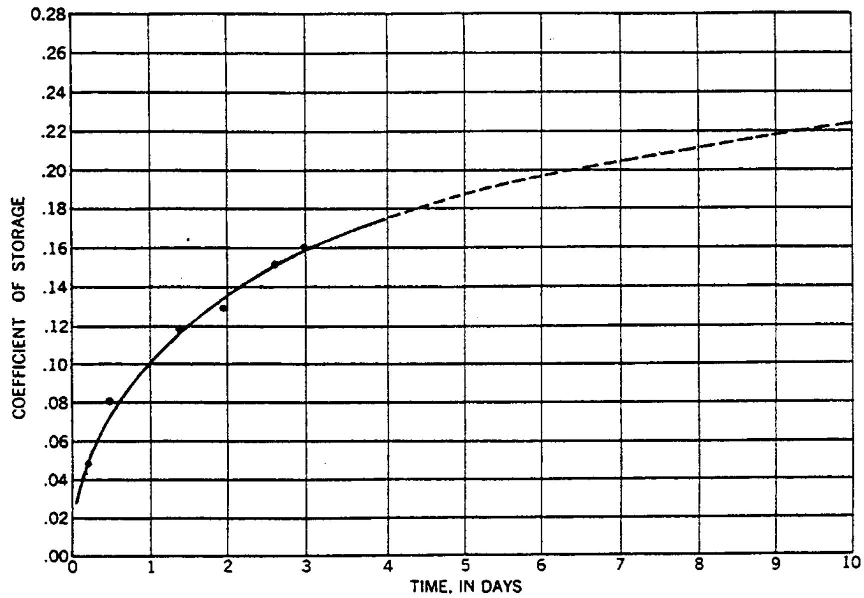

FIGURE 17.—Curve showing the increase in coefficient of storage with duration of pumping from well C3-68-11ada.

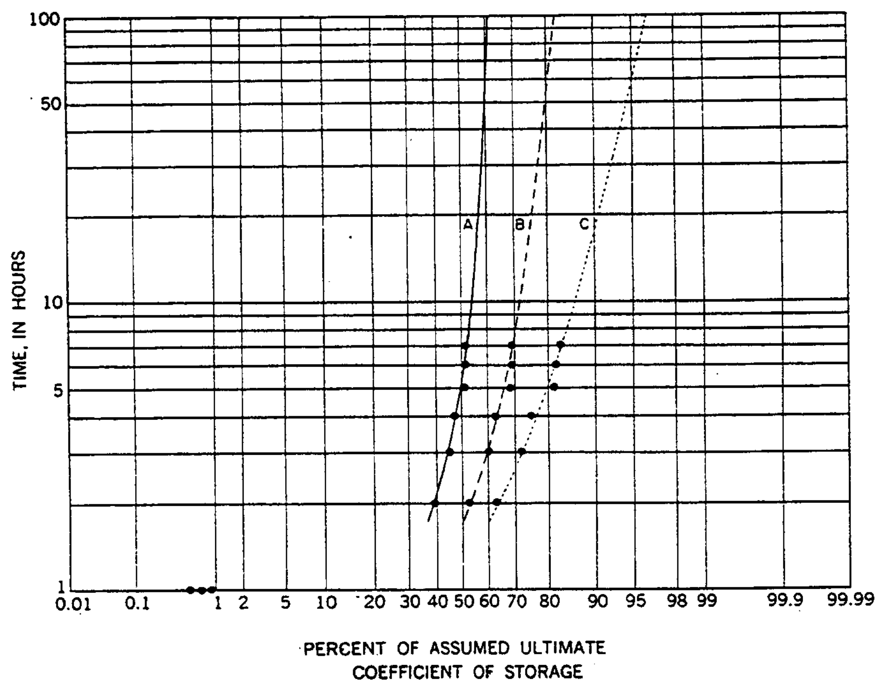

FIGURE 18.—Curves showing probable coefficient of storage at well C2-68-25add2 by use of logarithmic probability paper. *A*, assuming a coefficient of storage of 0.40; *B*, assuming a coefficient of storage of 0.30; *C*, assuming a coefficient of storage of 0.25.

hours; therefore, the probable value of the coefficient of storage of the valley-fill deposits at this site appears to be about 0.24 after long periods of pumping.

The coefficient of storage of the valley-fill deposits from the tests of wells B1-66-18ddd and B5-65-25bbb was 0.15. If these tests could have rùn longer without local effects from irrigation seepage, their coefficient of storage would have exceeded 0.15 and probably would have been not less than 0.20.

In addition to the use of pumping tests for determining the coefficient of storage of the valley-fill deposits, a representative sample of water-bearing material from test hole C2-67-23abc was analyzed in the Hydrologic Laboratory of the Geological Survey. The porosity of the sample was 34.7 percent, the specific retention was 6.5 percent, and the specific yield was 28.2 percent. The results of this test together with the results of the two most reliable pumping tests indicate that the coefficient of storage of the valley-fill deposits probably exceeds 0.20 in most places. The conservative value of 0.20 is used in computations throughout the report.

During this investigation, the relation between the specific capacity of wells and the coefficient of transmissibility of the aquifer was studied. Data from the 41 aquifer tests were used to construct a curve (fig. 19) showing the relation between the two values, which is more or less direct. The scatter of the data in figure 19 can be attributed to variations in the drawdown expressed as a percentage of total saturated thickness, duration of pumping, screen efficiency,

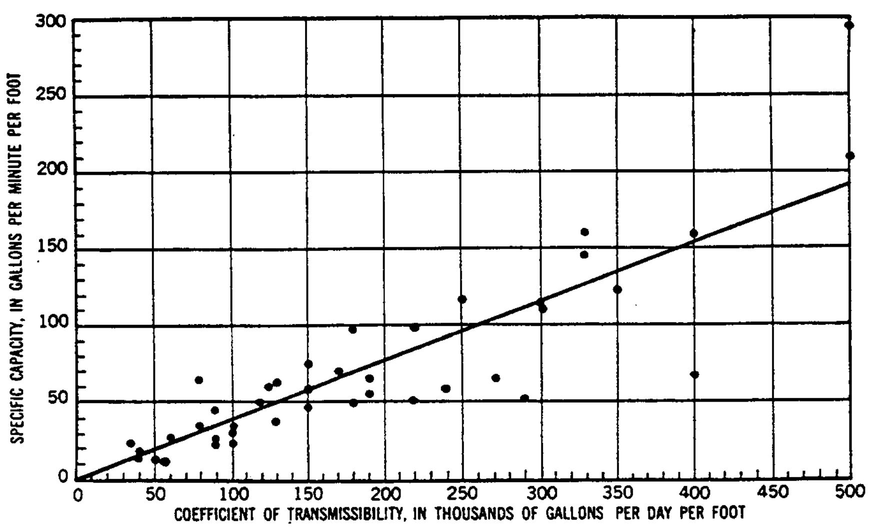

FIGURE 19.—Relation of the specific capacity of wells tapping the valley-fill deposits to the transmissibility of the valley-fill deposits in the vicinity of the wells.

and degree of well development. Formulas 1, 3, and 5 on pages 64 and 65 indicate that the specific capacity is directly proportional to the coefficient of transmissibility. Therefore, the relation may be expressed as a linear equation and the graph of the equation is a straight line. The slope of the line drawn through the data in figure 19 was computed by the straight-line method and the equation was found to be

$$T = 2{,}630 \times \text{specific capacity} \qquad (8)$$

This differs somewhat from the value obtained by Back (1957, p. 4–6, 30–32), because the water-level drawdown in several wells in the area is equivalent to more than half of the saturated thickness.

Data necessary for the calculation of specific capacity were obtained for 668 wells. Drawdowns in irrigation wells that yield about 1,000 gpm ranged from about 4 to 40 feet; their specific capacities, therefore, range from about 250 to 25 gpm per ft of drawdown. Although the drawdown in most wells was only a small fraction of the total saturated thickness, the drawdown in some exceeded 75 percent. A well in which the drawdown is only 10 percent of the saturated thickness would have a higher specific capacity, accordingly, than if it were pumped at 80-percent drawdown. From the specific capacity of a well, the coefficient of transmissibility of the aquifer in the vicinity of that well can be estimated from the curve in figure 19 or from equation 8. These indicate that a well having a specific capacity of 190, pumps water from an aquifer having a coefficient of transmissibility of about 500,000 gpd per ft. Together, plate 4 and figure 16 show that high coefficients of transmissibility generally characterize the deposits of sand and gravel in buried river channels; low coefficients of transmissibility generally indicate thin deposits of sand and gravel interlayered with lenses of silt and clay. The better producing wells are in areas of high transmissibility.

The relation between the coefficient of transmissibility of the valley-fill deposits and the yield of wells in the area, accompanied by a rating for irrigation, is shown as follows:

Coefficient of transmissibility (gpd per ft)	Yield (gpm)	Rating for irrigation
<25,000	<100	Poor.
25,000–100,000	100–500	Fair.
100,000–200,000	500–1, 000	Good.
>200,000	1, 000–2, 000	Excellent.

Although these ranges of the coefficient of transmissibility were arbitrarily chosen as the limits for the irrigation ratings, they are

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believed to be reasonably representative of the requirements for irrigation in this area.

QUANTITY OF GROUND WATER AVAILABLE FOR WITHDRAWAL

By E. D. Jenkins and W. W. Wilson

Most of the recoverable ground water that is stored in the report area, including practically all the ground water that is available to the large-capacity wells in the area, is in the valley-fill deposits. The approximate quantity of ground water available for withdrawal from the valley-fill deposits was determined by multiplying the volume of saturated material by a coefficient of storage of 0.20 (p. 74). The volume of saturated material was determined from the saturated-thickness map of the area (pl. 8). Even under ideal conditions, however, not all the ground water could be removed by pumping because a considerable amount will remain in the aquifer between the cones of depression of the wells after the water table has locally reached the base of the aquifer. The quantity of ground water that is represented by each foot of rise or decline of the water table was estimated and is shown in table 6 with the estimated quantity of ground water available for withdrawal. The quantity of ground water that theoretically could be removed by pumping is equal to the quantity of water in a surface reservoir 70 times the size of Barr Lake, which has a capacity of 28,000 acre-ft.

TABLE 6.—*Estimated quantity of ground water that could be removed from storage by pumping under ideal conditions*

[Based on a coefficient of storage of 0.20]

Area	Quantity of ground water represented by a 1-foot rise or decline of the water table (acre-ft)	Quantity of recoverable ground water in storage (acre-ft)
South Platte River valley:		
Denver to the base line	14, 000	300, 000
Base line to the north boundary of T. 3 N.	8, 000	250, 000
Northern boundary of T. 3 N. to Kuner	14, 000	760, 000
Beebe Draw between Barr Lake and Lower Latham Reservoir	8, 000	320, 000
Box Elder Creek valley	11, 000	320, 000
Total	55, 000	1, 950, 000

SUMMARY OF THE HYDROLOGY OF THE REPORT AREA

By E. D. JENKINS and W. W. WILSON

A summary of the hydrology of the report area (shown as accretions and depletions of total water supply) with reference to precipitation and evapotranspiration and to surface-water and ground-water discharge is given in table 7. The average annual precipitation in the area, which was obtained from U.S. Weather Bureau data, was multiplied by the total land area to determine the amount of water falling upon the area. The records of surface-water flow were obtained from the Surface Water Branch of the U.S. Geological Survey. Records of the amount of sewage discharged into the area were obtained from the city of Denver, and the flow of Latham Ditch was estimated from data supplied by the State Engineer's office.

The data for the quantity of ground-water underflow through the valley-fill deposits were taken from table 3. The average annual recharge to these deposits from precipitation was estimated by assuming an annual recharge rate of 10 percent of the total precipitation (p. 38). The average annual discharge from the valley-fill deposits by evapotranspiration in the stream-valley lowlands was determined by applying a consumptive use of 2 acre-ft per acre per yr (p. 47). The source of this water is ground water, irrigation water, and local precipitation. It was estimated that about 90 percent of the precipitation falling on the uplands would be lost by evaporation and transpiration.

TABLE 7.—*Summary of the hydrology of the report area*

	Acre-feet per year
Accretions to total water supply:	
Direct precipitation on the area (estimated)	670, 000
Surface-water inflow (measured):[1]	
South Platte River at Denver	223, 000
Return flow of Denver sewage	57, 500
Clear Creek	60, 000
St. Vrain Creek	135, 000
Big Thompson River	35, 000
Cache la Poudre River	50, 000
Other small streams (estimated)	5, 000
Ground-water inflow (computed):	
South Platte River valley	9, 600
Box Elder Creek valley	2, 100
Cache la Poudre River valley	5, 700
Other small valleys	3, 100
Total (rounded)	1, 260, 000
Depletions of total water supply:	
Evapotranspiration (estimated):	
Stream-valley lowlands (220,000 acres)	440, 000
Uplands (400,000 acres)	360, 000
Surface water:	
South Platte River near Kersey (measured)[1]	437, 000
Latham Ditch (estimated)	5, 900
Ground-water outflow (computed):	
South Platte River valley	12, 000
Box Elder Creek valley	1, 500
Total (rounded)	1, 260, 000

[1] Average discharge for a 30-yr period of record (1928–58).

The estimated quantities of water in table 7 necessarily are only approximate because the actual consumptive-use rates may differ greatly from those used here and because the acreages used are only rough approximations. Also, all the quantities vary from year to year, depending on the amount of precipitation, available surface water, and pumpage. Assuming, however, that the estimated quantities are reasonable, the summary suggests the general order of magnitude of water movement and distribution during an average year.

CHEMICAL QUALITY OF THE GROUND WATER

The economic welfare of the report area is closely associated with the utilization of ground water, especially for irrigation; however, very little information about the quality of the ground water was available for most of the area. Some information on the quality of the water in the vicinity of Derby, Colo., which is only a small part of the area, was available from a study made by the U.S. Geological Survey (Petri and Smith, 1959).

For the present investigation, ground-water samples for chemical analysis were obtained between September 1957 and March 1958. All sampling locations are shown on plate 9, which shows also the relation of the wells to topography and to the locations of principal irrigation canals and ditches. Although no samples from the South Platte River or its principal tributaries were obtained specifically for this investigation, the locations for which water-quality data are available have been included on plate 9.

Samples of water from the valley-fill deposits generally were collected from wells at least 200 feet from canals or ditches because such wells probably are not unduly affected by recharge from these surface sources. Samples of water from bedrock were taken from wells drilled after 1950 because such wells are less likely to have corroded or leaking casings, and they were taken only from wells for which logs were available. Before the samples were collected, the wells generally were pumped a minimum of 5 minutes to insure freshness of the samples.

CHEMICAL COMPOSITION AND MINERALIZATION

Water always contains some dissolved material. The principal dissolved materials in ground water normally are the constituents that have resulted from the dissolution of minerals in the rocks with which the water has been in contact. The kinds and concentrations of the various mineral constituents in the water determine the chemical quality of the water.

Specific conductance is used in this report to denote the degree of mineralization of the water; the concentration of dissolved solids ordinarily would be used, but it was not determined for many of the samples. Specific conductance is a measure of the ability of the water to conduct an electrical current and is reported in micromhos per centimeter at 25°C; a micromho is a reciprocal ohm $\times 10^6$. Water free of dissolved minerals is a poor conductor, but water that contains dissolved minerals is a good conductor; the more dissolved minerals in the water, within certain limits, the better the water will conduct electricity.

Concentrations of the various constituents are given in the tables in parts per million (ppm). A part per million is a unit weight of the constituent in a million unit weights of water. The concentrations, however, are shown in equivalents per million (epm) on some of the illustrations. The term "equivalent" is used in chemistry to denote equal combining power. An equivalent per million is one combining weight of a constituent in a million unit weights of water. One equivalent per million of a positively charged ion will react with one equivalent per million of a negatively charged ion.

Parts per million are converted to equivalents per million by multiplying by the following factors:

Cation	*Factor*	*Anion*	*Factor*
Calcium (Ca^{2+})	0.04990	Bicarbonate (HCO_3^-)	.01639
Magnesium (Mg^{2+})	.08224	Carbonate (CO_3^{-2})	0.03333
Sodium (Na^+)	.04350	Sulfate (SO_4^{-2})	.02082
Potassium (K^+)	.02558	Chloride (Cl^-)	.02820
		Fluoride (F^-)	.05263
		Nitrate (NO_3^-)	.01613

WATER FROM THE VALLEY-FILL DEPOSITS

Chemical analyses of water from the valley-fill deposits (table 8) indicate that the degree of mineralization and the chemical composition of the water range between wide limits. For example, the specific conductance of the water ranged from 486 to 13,100 micromhos per cm; concentrations of calcium, from 25 to 984 ppm; and concentrations of sulfate, from 15 to 5,740 ppm.

A disproportionately large number of samples were obtained from wells in secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W. during a previous study in the vicinity of Derby. The chemical composition of much of the water from this area is significantly different from that in most of the report area; therefore, data from this area where sampling density is high are treated separately in some of the figures.

TABLE 8.—*Chemical analyses of*

[D, domestic; I, irrigation; In, industrial; Iu, irrigation (unused); M, municipal; N, none; O-GS,

Well	Well depth (feet)	Use	Date of collection	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
B1-64-18ccd	------	I	9-10-57	------	41	------	258	60	170	9.7	320
B1-65-24cb	------	D	9-10-57	------	------	------	------	------	121	3.7	282
-30dcb	54.3	I	9-10-57	------	19	0.03	110	28	127	2.6	324
B1-66-5bdc	------	I	9-14-56	------	------	------	------	------	------	------	------
-8bcb	------	I	9-12-56	------	------	------	------	------	------	------	------
-18ddc	49.9	I	9-17-57	59	------	------	------	------	175	5.1	334
-18ddd	38.6	I	9-14-56	------	------	------	------	------	------	------	------
-19abd	32.7	I	9-14-56	------	------	------	------	------	------	------	------
			9-11-57	55	------	------	------	------	148	5.7	404
-19bbc	23.4	I	9-14-56	------	------	------	------	------	------	------	------
-29bbc	34.4	I	9-14-56	------	------	------	------	------	------	------	------
-31cdd	31.8	I	9-16-57	------	19	.01	170	31	170	9.1	414
-31ddc	36.1	I	9-14-56	------	------	------	------	------	------	------	------
-32cdd	------	D	9-18-57	------	------	------	------	------	103	6.6	249
B1-67-3aaa	25	D, S	9-12-57	56	25	.04	185	80	280	2.8	446
-23bcb	------	D	9-12-57	56	21	.13	155	56	284	3.6	464
-36cdd [1]	22.1	S, O-GS	9-16-57	------	------	------	------	------	103	20	401
B2-65-13bcd	51.0	I	9-17-57	------	26	.04	131	26	82	4.4	242
-15add	67	I	9-17-57	------	------	------	------	------	182	4.5	264
-16ada	------	D	9-17-57	------	------	------	------	------	96	2.4	255
-16bcc	82.5	I	9-17-57	------	21	.01	160	62	236	9.2	290
B2-66-6dcd	------	I	9-17-57	------	------	------	------	------	------	------	------
-19cca	28.5	I	9-21-56	------	------	------	------	------	------	------	------
-20cac	56.8	I	9-21-56	------	------	------	------	------	------	------	------
B2-67-24ada	19.5	I	9-17-57	57	------	------	------	------	163	4.7	308
B3-64-17cdd	65	I	9-10-57	------	26	.03	310	62	324	7.3	322
B3-65-22ccd	78.7	I	9-10-57	55	19	.28	230	79	302	5.3	261
B3-66-6cdd1	52.4	I	9-17-56	------	------	------	------	------	------	------	------
-7cdd	49.1	I	9-17-56	------	------	------	------	------	------	------	------
-30bac	55.4	I	9-17-56	------	------	------	------	------	------	------	------
-31caa	------	D	9-17-57	------	------	------	------	------	119	6.3	251
B3-67-2dcd	27	I	9-17-56	------	------	------	------	------	------	------	------
-10cdd2	76.5	I	9- 8-57	56	19	.01	98	26	100	3.7	250
-12ccc	55.3	I	9-17-56	------	------	------	------	------	------	------	------
-13add	54	I	9- 8-57	------	23	.01	102	27	108	5.9	275
-13bcd	31.8	I	9- 8-57	56	------	------	------	------	102	4.0	247
-22adc1	81.5	I	9- 8-57	56	------	------	------	------	122	3.2	305
-26dbc	65	I	9-12-56	------	------	------	------	------	------	------	------
B4-64-14cdc	68.5	I	9- 7-57	53	36	.04	303	86	332	6.3	470
-15dcc	52.9	I	9- 7-57	65	26	.04	77	18	113	3.7	268
-22ddc	61.7	I	9- 7-57	------	------	------	------	------	219	5.7	445
B4-65-3ccc	89	I	9- 7-57	54	------	------	------	------	122	3.9	396
-4ccc1	45	I	9- 8-57	54	------	------	------	------	139	5.0	320
-5abc	------	I	9-19-56	------	------	------	------	------	------	------	------
-6dac	------	I	9-20-56	------	------	------	------	------	------	------	------
-6dad	83	I	9- 8-57	53	20	0.01	168	57	155	4.5	412
-8bbb	------	I	9-24-57	------	------	------	------	------	106	3.8	313
-8dcb	------	I	9-19-56	------	------	------	------	------	------	------	------
-10dcc	60	I	9- 7-57	56	------	------	------	------	89	4.2	337
-11cdc	72	I	9- 7-57	54	21	.08	180	74	214	4.8	368
-15bac	------	I	9-19-56	------	------	------	------	------	------	------	------
-19cda [1]	55.5	I	9-19-56	------	------	------	------	------	------	------	------
B4-66-2ccc	62.9	I	9-19-56	------	------	------	------	------	------	------	------
-8ddd	56.5	I	9-19-56	------	------	------	------	------	------	------	------
-10bcd	------	I	9-18-56	------	------	------	------	------	------	------	------
-12dcc	100	I	9-20-56	------	------	------	------	------	------	------	------
-14bcc1	69	I	9-17-57	57	20	.02	129	31	113	4.4	302
-17bcb2	------	I	9-19-56	------	------	------	------	------	------	------	------
-19dcb	57.4	I	9-18-56	------	------	------	------	------	------	------	------
-22bbb	------	I	9-18-56	------	------	------	------	------	------	------	------
-26ddd1	64.6	I	9-18-56	------	------	------	------	------	------	------	------
-27cdd1	45.3	I	9-18-56	------	------	------	------	------	------	------	------
-28bba	------	I	9-18-56	------	------	------	------	------	------	------	------
-29dcc1	100.6	I	9-18-56	------	------	------	------	------	------	------	------
-30cdd2	------	I	9-17-56	------	------	------	------	------	------	------	------
-30ddd	92	I	9-17-57	57	------	------	------	------	108	5.2	281
-32ccb	66.6	I	9-17-56	------	------	------	------	------	------	------	------
-33ddd1	39.2	I	9-18-56	------	------	------	------	------	------	------	------
B4-67-12cdd	------	I	9- 8-57	54	32	.02	134	55	106	3.0	314
-25acc1	46.3	I	9-18-56	------	------	------	------	------	------	------	------
-35ada	49.6	I	9-17-56	------	------	------	------	------	------	------	------
B5-64-3ccc	70	I	9- 7-57	53	28	.02	230	121	319	8.3	383
-16bbb	83.8	I	9-20-56	------	------	------	------	------	------	------	------
-19abc	------	I	9-20-56	------	------	------	------	------	------	------	------
-22dab2	66.7	I	9- 7-57	47	28	.01	168	68	183	5.4	314
-25dba	------	I	9-21-56	------	------	------	------	------	------	------	------

See footnote at end of table.

water from the valley-fill deposits

observation well of U.S. Geol. Survey; S, stock. Results in parts per million except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C.	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C.)	pH
868	64	0.5	16	0.01	1,640	1,670	892	630	29	2.5	2,050	7.5
--	--	--	--	.20	--	--	410	179	39	2.6	1,250	7.5
225	102	2.3	8.2	.30	--	802	388	122	41	2.8	1,240	7.9
--	145	--	--	--	--	--	--	--	--	--	1,790	--
--	135	--	--	--	--	--	--	--	--	--	1,670	--
--	--	--	--	--	--	--	406	132	48	3.8	1,520	7.5
--	126	--	--	--	--	--	--	--	--	--	1,420	--
--	135	--	--	--	--	--	--	--	--	--	1,570	--
--	--	--	--	--	--	--	535	204	37	2.8	1,570	7.9
--	89	--	--	--	--	--	--	--	--	--	1,030	--
--	131	--	--	--	--	--	--	--	--	--	1,510	--
343	122	1.2	40	.64	1,110	1,150	552	213	40	3.2	1,660	7.5
--	130	--	--	--	--	--	--	--	--	--	1,490	--
--	--	--	--	--	--	--	276	72	44	2.7	972	7.7
730	160	.8	23	.44	1,710	1,770	792	426	43	4.3	2,400	8.0
620	119	1.6	15	.51	1,500	1,530	618	238	50	5.0	2,150	8.1
--	--	--	--	--	--	--	415	86	49	4.1	1,570	7.8
295	58	.9	28	.08	--	784	434	236	29	1.7	1,120	7.8
--	--	--	--	--	--	--	577	360	40	3.3	1,730	7.9
--	84	--	--	.14	--	--	394	185	34	2.1	1,130	7.9
705	130	1.8	19	.42	1,490	1,540	654	416	44	4.0	2,080	7.9
--	93	--	--	--	--	--	--	--	--	--	1,220	--
--	102	--	--	--	--	--	--	--	--	--	1,340	--
--	110	--	--	--	--	--	--	--	--	--	1,400	--
--	111	--	--	.23	--	--	448	195	44	3.3	1,480	7.5
1,140	151	.7	14	.18	2,190	2,320	1,030	766	40	4.4	2,840	7.4
980	186	1.4	19	.31	1,950	2,080	898	684	42	4.4	2,630	7.5
--	78	--	--	--	--	--	--	--	--	--	1,170	--
--	96	--	--	--	--	--	--	--	--	--	1,270	--
--	100	--	--	--	--	--	--	--	--	--	1,220	--
--	--	--	--	--	--	--	341	135	43	2.8	1,150	7.7
--	88	--	--	--	--	--	--	--	--	--	1,150	--
229	69	1.0	24	.13	--	705	352	147	38	2.3	1,070	7.2
--	88	--	--	--	--	--	--	--	--	--	1,170	--
210	88	1.4	19	.20	--	745	364	138	39	2.5	1,140	7.2
--	--	--	--	--	--	--	289	86	43	2.6	988	7.6
--	--	--	--	--	--	--	428	178	38	2.6	1,250	8.0
--	78	--	--	--	--	--	--	--	--	--	1,200	--
1,070	204	.8	12	.28	2,280	2,390	1,110	725	39	4.3	2,990	7.7
196	55	1.7	7.4	.24	--	635	265	45	48	3.0	963	7.6
--	--	--	--	.28	--	--	658	293	42	3.7	1,980	8.1
286	84	--	--	--	--	--	508	183	34	2.4	1,390	8.1
--	--	--	--	--	--	--	364	102	45	3.2	1,230	8.1
--	56	--	--	--	--	--	--	--	--	--	1,480	--
--	94	--	--	--	--	--	--	--	--	--	1,360	--
438	98	2.1	30	0.23	1,180	1,240	652	314	34	2.6	1,710	7.6
--	--	--	--	--	--	--	420	163	35	2.2	1,200	8.1
--	91	--	--	--	--	--	--	--	--	--	1,340	--
206	67	--	--	--	--	--	392	116	33	2.0	1,090	8.0
655	143	1.4	18	.28	1,490	1,600	752	450	38	3.4	2,130	7.6
--	82	--	--	--	--	--	--	--	--	--	1,250	--
--	95	--	--	--	--	--	--	--	--	--	1,280	--
--	75	--	--	--	--	--	--	--	--	--	1,200	--
--	80	--	--	--	--	--	--	--	--	--	1,170	--
--	86	--	--	--	--	--	--	--	--	--	1,200	--
--	80	--	--	--	--	--	--	--	--	--	1,330	--
260	88	.8	47	.15	--	864	450	202	35	2.3	1,290	7.9
--	79	--	--	--	--	--	--	--	--	--	1,250	--
--	80	--	--	--	--	--	--	--	--	--	1,170	--
--	95	--	--	--	--	--	--	--	--	--	1,410	--
--	65	--	--	--	--	--	--	--	--	--	908	--
--	78	--	--	--	--	--	--	--	--	--	1,230	--
--	126	--	--	--	--	--	--	--	--	--	1,860	--
--	92	--	--	--	--	--	--	--	--	--	1,430	--
--	76	--	--	--	--	--	--	--	--	--	1,160	--
--	--	--	--	--	--	--	422	192	35	2.3	1,220	7.8
--	92	--	--	--	--	--	--	--	--	--	1,350	--
--	81	--	--	--	--	--	--	--	--	--	1,120	--
453	17	.6	27	.24	982	1,020	562	305	29	1.9	1,350	7.8
--	94	--	--	--	--	--	--	--	--	--	1,520	--
--	84	--	--	--	--	--	--	--	--	--	1,290	--
1,260	55	1.4	13	.53	2,220	2,380	1,070	756	39	4.2	2,800	7.5
--	69	--	--	--	--	--	--	--	--	--	1,980	--
--	76	--	--	--	--	--	--	--	--	--	1,990	--
670	61	1.6	30	.28	1,370	1,420	700	443	36	3.0	1,870	7.9
--	80	--	--	--	--	--	--	--	--	--	2,470	--

TABLE 8.—*Chemical analyses of water*

[D, domestic; I, irrigation; In, industrial; Iu, irrigation (unused); M, municipal; N, none; O-GS,

Well	Well depth (feet)	Use	Date of collection	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
B5-65-6bbc	12.0	I	9- 6-57	61					152	7.3	362
-12dbc		I	9-21-56								
-15abc	50	I	9- 7-57	60					118	6.9	303
-15bcc		Iu	9-20-56								
-22dad		I	9-20-56								
-23acc		I	9- 7-57	55					182	7.1	418
-25bbb	44.6	I	9- 7-57	53	45	0.15	228	110	336	4.8	502
-31bcd	40	I	9- 8-57	55					112	3.3	322
-34cad		I	9-19-56								
B6-64-35baa		I	9- 7-57		31	.80	325	552	1,600	23	478
B6-65-24dcd		I	9- 6-57	56	49	.09	245	53	149	12	368
-28aba		I	9- 6-57		41	.01	238	59	133	10	356
-29acb		I	9- 6-57	53	35	.00	210	50	98	6.4	316
-31ca		I	9- 6-57	56					189	4.5	352
B6-65-31cdb1	14	S	9- 6-57	61	28	.01	160	78	121	6.2	344
-31cdb2	90+	N	9- 6-57	56	29		25	6.2	147	2.3	[1] 100
C1-66-1baa	70	I	9-10-57	56	22	.00	88	39	92	4.1	316
-6acd	41.3	I	9-16-57	55					185	6.6	355
-18bdc	35.0	I	9-12-56								
-20bbd1	36	S, I	9-18-57						144	6.0	425
-29cac	45	S	9-18-57						136	3.3	400
-30abd		I	9-13-56								
-32aad		S	9-18-57		24	.00	130	40	113	4.5	330
C1-67-1dcb		I	9-14-56								
-13caa	31.7	I	9-13-56								
-24aad	49	I	9-12-56								
-26aad	41.1	I	9-13-56								
-34da1	10	I	9-10-55	63							
-35dca	40.0	I	9-10-55	56							
-36dcb1	43	I	9-11-55	55							
C2-65-12bac	85.1	I	9-16-57	54					32	4.5	210
-12ccc	64.0	I	9-16-57		31	.02	93	14	41	5.2	230
C2-66-6cb1	40	D	9-11-55	64							
C2-67-1aad	28.4	I	9-11-55	60							
-1bbb	45	I	9-10-55	53							
-1ccc1	42.8	I	9-15-55	55							
			3- 9-56	54							
-2bac	41.0	I	9-10-55	56							
-2cdc	48.6	I	9-12-55	58							
			3-10-56								
			6- 4-56	54							
-2ddd [1]	39.1	I	9-12-55	55							
			3- 9-56								
-3cba	12	I	10- 8-55	61	24		134	31	111	6.0	325
-3ccc2	10.8	I	10- 8-55	62	26		136	33	108	4.1	296
			3-10-56	44							
			6- 3-56								
-3cdd	46	I	9-15-55	54							
			3-10-56	50							
			6- 3-56	54							
-7ddd		I	9-11-57						156	8.0	331
-8bc1	33	I	11-17-55		17		114	9.6	53	.8	389
-9add	13.1	I	9-15-55	57	25		213	62	141	3.2	302
			11-13-55								
			3-12-56	50							
			6- 3-56								
-9cd1	12	I	10- 8-55	63	19		61	17	110	6.7	248
-9daa1	23	I	9-15-55	55	24		269	76	158	3.3	302
			3-12-56								
			6- 3-56	53							
-9 daa2	50	D	3-12-56								
-9dad1	50	I	9-15-55	54	23		228	65	158	3.9	313
			6- 3-56	53							
-9dad2	45	D	9-12-55				270	74	179		308
			11-15-55				242	60	177	3.0	307
			3-12-56								
-9dc	68	D	10- 8-55		26		161	47	76	2.3	300
			11-13-55								
			3-12-56								
			6- 3-56								
-9ddb	46.3	I	9-15-55	54	24		188	47	110	2.4	331
			6- 3-56								
-10aba2	47	I	9-15-55	54							

See footnote at end of table.

from the valley-fill deposits—Continued

observation well of U.S. Geol. Survey; S, stock. Results in parts per million except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C.	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C.)	pH
--------	34	--------	--------	--------	--------	--------	779	482	30	2.4	1,840	7.6
--------	62	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,920	----
--------	--------	--------	--------	--------	--------	--------	665	416	28	2.0	1,540	7.6
--------	21	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,570	----
--------	68	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,730	----
--------	--------	--------	--------	--------	--------	--------	703	360	36	3.0	1,880	8.1
1,070	116	1.9	15	0.47	2,170	2,310	1,020	608	42	4.6	2,860	8.0
--------	--------	--------	--------	--------	--------	--------	459	195	34	2.3	1,270	8.1
--------	54	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,680	----
5,740	274	3.3	3.2	.66	8,790	9,270	3,080	2,690	53	13	9,440	7.7
772	26	.9	28	.29	1,520	1,540	828	506	28	2.2	1,910	7.7
743	34	.5	28	.28	1,460	1,520	836	544	25	2.0	1,870	7.4
599	23	.4	39	.39	1,220	1,260	728	469	22	1.6	1,570	7.6
--------	--------	--------	--------	--------	--------	--------	1,110	817	27	2.5	2,360	7.6
641	22	0.8	9.8	.32	1,240	1,300	720	438	27	2.0	1,640	7.4
289	28	.4	1.1	.10	--------	580	88	6	78	6.8	874	8.4
162	95	1.9	24	.26	--------	690	380	121	34	2.1	1,100	7.9
--------	--------	--------	--------	--------	--------	--------	624	333	39	3.2	1,850	7.6
--------	113	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,500	----
--------	--------	--------	--------	--------	--------	--------	493	144	38	2.8	1,460	7.9
--------	--------	--------	--------	--------	--------	--------	539	211	35	2.5	1,520	7.9
--------	128	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,470	----
284	88	1.9	45	.25	--------	908	488	217	33	2.3	1,340	7.9
--------	120	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,290	----
--------	113	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,480	----
--------	109	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,430	----
--------	99	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,330	----
--------	97	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,280	----
--------	104	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,210	----
--------	84	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,110	----
--------	--------	--------	--------	.04	--------	--------	245	73	22	.9	627	7.6
128	32	.5	15	.05	--------	472	288	99	23	1.0	718	7.7
--------	129	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,350	----
--------	87	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,000	----
--------	105	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,210	----
--------	132	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,410	----
480	149	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,820	----
--------	85	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,390	----
--------	123	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,680	----
--------	102	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,390	----
--------	110	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,370	----
--------	108	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,420	----
--------	119	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,820	----
243	106	1.6	46	.25	--------	892	464	197	34	2.2	1,340	7.4
220	144	1.2	30	.22	--------	896	474	231	33	2.2	1,370	7.2
--------	258	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,870	----
--------	220	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,770	----
--------	112	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,470	----
--------	111	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,480	----
--------	109	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,490	----
--------	--------	--------	--------	--------	--------	--------	464	193	42	3.1	1,440	8.0
101	10	1.6	1.1	.12	--------	500	324	5	26	1.3	782	7.4
305	356	1.8	27	.32	1,280	1,440	786	538	28	2.2	2,120	7.4
--------	452	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,450	----
--------	400	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,290	----
--------	460	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,440	----
107	87	1.0	26	.19	--------	557	223	20	51	3.2	950	7.4
338	506	1.6	25	.28	1,550	1,740	984	736	26	2.2	2,550	7.3
--------	410	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,360	----
--------	620	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,910	----
--------	446	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,380	----
373	371	1.6	21	.33	1,400	1,480	836	579	29	2.4	2,250	7.4
--------	720	--------	--------	--------	--------	--------	--------	--------	--------	--------	3,160	----
548	370	1.6	24	--------	--------	1,830	978	725	29	2.5	2,470	7.7
468	326	1.2	24	--------	--------	1,570	850	598	31	2.6	2,310	7.4
--------	550	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,780	----
300	136	1.2	19	.15	917	1,010	596	350	22	1.4	1,440	7.6
--------	137	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,450	----
--------	141	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,420	----
--------	144	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,430	----
280	236	1.4	20	.29	1,070	1,130	664	393	26	1.9	1,720	7.3
--------	320	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,010	----
--------	102	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,220	----

TABLE 8.—*Chemical analyses of water*

[D, domestic; I, irrigation; In, industrial; Iu, irrigation (unused); M, municipal; N, none; O-GS,

Well	Well depth (feet)	Use	Date of collection	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
C2-67-10abd	44.1	I	9-15-55	62	22	------	147	42	114	2.7	380
			3-10-56	------	------	------	------	------	------	------	------
			6-4-56	------	------	------	------	------	------	------	------
-10add1	49.4	I	9-15-55	54	24	------	121	36	100	3.0	379
			6-4-56	54	------	------	------	------	------	------	------
-10bdb1	32.8	I	9-20-55	55	25	------	181	52	134	2.8	348
			3-10-56	51	------	------	------	------		------	------
			6-3-56	52	------	------	------	------	------	------	------
-10ccc1	59	D	9-20-55	------	29	------	250	75	152	3.4	324
			11-12-55	------	------	------	------	------	------	------	------
			3-12-56	------	------	------	------	------	------	------	------
			6-3-56	------	------	------	------	------	------	------	------
			9-11-57	------	27	0.02	475	116	254	5.0	310
-10ccd	34.4	O-GS	3-12-56	------	------	------	------	------	------	------	------
			5-16-56	------	------	------	496	126	260	6.4	304
			6-3-56	------	------	------	------	------	------	------	------
-10cdd	39.8	I	9-12-55	54	35	------	233	59	139	2.8	352
			11-25-55	------	24	------	170	43	121	2.4	392
			3-15-56	54	------	------	------	------	------	------	------
			6-3-56	54	------	------	------	------	------	------	------
-10dcc1	41	I	11-13-55	------	------	------	------	------	------	------	------
			3-15-56	54	------	------	------	------	------	------	------
			6-3-56	------	------	------		------	------	------	------
-10dcc2	39.5	I	11-17-54	------	------	------	136	35	161	3.4	426
			9-12-55	54	------	------	135	44	136	2.2	408
			11-13-55	54	------	------	------	------	------	------	------
			3-15-56	------	------	------	------	------	------	------	------
			6-3-56	------	------	------	------	------	------	------	------
-10ddb1	50	I	9-12-55	54	27	------	133	37	107	3.2	406
			6-2-56	54	------	------	------	------	------	------	------
-11aab	44	D	9-11-55	58	------	------	------	------	------	------	------
			3-9-56	------	------	------	------	------	------	------	------
-11aad1	42.9	I	9-11-55	------	------	------	------	------	------	------	------
			6-4-56	------	------	------	------	------	------	------	------
-11adb	41.1	I	9-11-55	54	------	------	------	------	------	------	------
-11bac1	51.9	I	9-12-55	56	------	------	------	------	------	------	------
-11bda1	56.3	I	3-10-56	53	------	------	------	------	------	------	------
			6-4-56	54	------	------	------	------	------	------	------
-11bda2	63	I	9-12-55	56	------	------	------	------	------	------	------
-11dbd	50.0	I	9-12-55	55	23	------	128	37	116	5.4	460
			3-9-56	53	------	------	------	------	------	------	------
			6-4-56	53	------	------	------	------	------	------	------
-12abd	30.8	Iu	11-9-55	51	------	------	------	------	------	------	------
			3-9-56	51	------	------	------	------	------	------	584
-13cad	40.5	Iu	9-15-55	------	35	------	122	75	498	40	1,710
			3-9-56	------	------	------	------	------	------	------	------
-14aaa	26.0	N	10-5-55	57	15	------	114	24	428	5.0	230
			3-9-56	------	------	------	------	------	------	------	238
-14bba	51.1	I	9-9-55	53	26	------	208	61	244	3.7	406
			3-9-56	55	------	------	------	------	------	------	------
			6-3-56	52	------	------	------	------	------	------	------
-14bbb2	54.0	I	9-9-55	53	28	------	183	58	195	3.1	458
			3-9-56	55	------	------	------	------	------	------	------
			6-3-56	52	------	------	------	------	------	------	------
			9-11-57	------	------	------	------	------	239	4.7	405
-15adb	46.5	I	9-17-55	57	22	------	161	40	144	3.0	414
			3-9-56	59	------	------	------	------	------	------	------
			6-4-56	------	------	------	------	------	------	------	------
-15bad	40.0	I	9-12-55	56	22	------	327	81	211	4.2	339
			11-13-55	54	------	------	------	------	143	3.1	384
			3-8-56	------	------	------	------	------	------	------	------
			6-3-56	53	------	------	------	------	------	------	------
-15bda1	40.7	I	9-12-55	55	22	------	320	82	210	4.1	326
			11-13-55	56	------	------	------	------	155	3.6	380
			3-8-56	------	------	------	------	------	------	------	------
			6-3-56	------	------	------	------	------	------	------	------
			9-11-57	------	27	.01	290	72	180	3.2	378
-15bda2	47.8	I	9-17-55	------	23	------	142	35	160	2.7	438
			3-9-56	------	------	------	------	------	164	------	413
			6-4-56	------	------	------	------	------	------	------	------
			9-11-57	54	------	------	------	------	194	2.5	380

See footnote at end of table.

from the valley-fill deposits—Continued

observation well of U.S. Geol. Survey; S, stock. Results in parts per million except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C.)	pH
					Calculated	Residue on evaporation at 180° C.						
303	112	1.2	18	0.25	----	974	538	226	31	2.1	1,450	7.5
----	110	----	----	----	----	----	----	----	----	----	1,390	----
----	114	----	----	----	----	----	----	----	----	----	1,370	----
183	105	1.0	20	.25	----	812	448	137	32	2.1	1,250	7.4
----	106	----	----	----	----	----	----	----	----	----	1,300	----
305	238	1.6	14	.31	1,130	1,260	666	381	30	2.3	1,820	7.3
----	265	----	----	----	----	----	----	----	----	----	1,860	----
----	420	----	----	----	----	----	----	----	----	----	2,360	----
288	465	1.6	16	.29	1,440	1,900	932	666	26	2.2	2,470	7.6
----	566	----	----	----	----	----	----	----	----	----	2,610	----
----	670	----	----	----	----	----	----	----	----	----	2,890	----
----	680	----	----	----	----	----	----	----	----	----	3,010	----
345	1,100	1.2	30	.28	2,510	2,960	1,660	1,410	25	2.7	4,240	7.8
----	790	----	----	----	----	----	----	----	----	----	3,340	----
362	1,200	----	18	----	----	----	1,760	1,510	24	2.7	4,540	7.3
----	1,180	----	----	----	----	----	----	----	----	----	4,470	----
323	343	1.6	16	.30	1,330	1,570	826	537	27	2.1	2,150	7.5
256	172	1.4	24	.24	1,010	1,060	600	279	30	2.1	1,600	7.3
----	128	----	----	----	----	----	----	----	----	----	1,450	----
----	126	----	----	----	----	----	----	----	----	----	1,510	----
----	148	----	----	----	----	----	----	----	----	----	1,740	----
----	130	----	----	----	----	----	----	----	----	----	1,560	----
----	108	----	----	----	----	----	----	----	----	----	1,320	----
296	106	1.6	14	----	----	----	484	134	42	3.2	1,490	7.3
298	107	1.6	16	.29	1,000	1,080	516	181	36	2.6	1,480	7.5
----	107	----	----	----	----	----	----	----	----	----	1,520	----
----	101	----	----	----	----	----	----	----	----	----	1,440	----
----	100	----	----	----	----	----	----	----	----	----	1,360	----
195	124	1.2	18	.24	----	934	486	153	32	2.1	1,360	7.6
----	102	----	----	----	----	----	----	----	----	----	1,250	----
----	122	----	----	----	----	----	----	----	----	----	1,700	----
385	122	----	----	----	----	----	----	----	----	----	1,670	----
----	125	----	----	----	----	----	----	----	----	----	1,840	----
----	118	----	----	----	----	----	----	----	----	----	1,860	----
----	121	----	----	----	----	----	----	----	----	----	1,820	----
----	129	----	----	----	----	----	----	----	----	----	1,460	----
633	111	----	----	----	----	----	----	----	----	----	2,000	----
----	146	----	----	----	----	----	----	----	----	----	1,790	----
----	140	----	----	----	----	----	----	----	----	----	1,500	----
134	130	1.2	32	.26	----	902	472	95	34	2.3	1,380	7.6
----	126	----	----	----	----	----	----	----	----	----	1,550	----
----	150	----	----	----	----	----	----	----	----	----	1,360	----
----	212	.8	----	----	----	----	----	----	----	----	1,530	----
17	220	----	.6	----	----	----	158	0	----	10	1,580	8.0
15	194	1.4	.5	.67	1,820	----	612	0	62	8.8	3,030	7.8
----	203	----	----	----	----	----	----	----	----	----	2,530	----
840	184	5.2	11	.48	1,740	1,770	382	193	71	9.5	2,520	7.7
938	210	----	----	----	----	----	432	237	----	----	2,820	7.7
525	290	.8	12	.44	1,570	1,670	770	437	41	3.8	2,380	7.6
530	330	----	----	----	----	----	----	----	----	----	2,510	----
----	280	----	----	----	----	----	----	----	----	----	2,320	----
530	130	1.2	13	.36	1,370	1,460	696	320	38	3.2	1,980	7.5
610	150	----	----	----	----	----	----	----	----	----	2,180	----
----	142	----	----	----	----	----	----	----	----	----	2,100	----
----	252	----	----	----	----	----	759	427	40	3.8	2,250	8.0
340	114	1.2	32	.24	1,060	1,110	568	229	35	2.6	1,590	7.5
----	91	----	----	----	----	----	----	----	----	----	1,310	----
----	108	----	----	----	----	----	----	----	----	----	1,720	----
365	670	1.2	26	.33	1,880	2,050	1,150	872	28	2.7	3,130	7.2
343	225	1.2	31	----	----	1,290	720	405	30	2.3	1,910	7.3
----	121	----	----	----	----	----	----	----	----	----	1,430	----
----	117	----	----	----	----	----	----	----	----	----	1,400	----
405	640	.8	30	.33	1,880	2,040	1,140	873	29	2.7	3,050	7.3
348	260	.8	32	----	----	1,380	744	432	31	2.5	2,030	7.3
----	126	----	----	----	----	----	----	----	----	----	1,520	----
----	130	----	----	----	----	----	----	----	----	----	1,400	----
408	450	1.0	32	.34	1,650	1,880	1,020	710	28	2.5	2,600	7.8
290	137	1.6	17	.35	1,030	1,040	498	139	41	3.1	1,580	7.4
345	130	----	----	----	----	1,120	546	207	40	3.1	1,670	7.3
----	188	----	----	----	----	----	----	----	----	----	1,930	----
----	136	----	----	----	----	----	601	289	41	3.4	1,800	8.0

TABLE 8.—*Chemical analyses of water*

[D, domestic; I, irrigation; In, industrial; Iu, irrigation (unused); M, municipal; N, none; O-GS,

Well	Well depth (feet)	Use	Date of collection	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
C2-67-15bdc	34.5	I	9-12-55	53	23	------	365	98	232	5.1	335
			11-12-55	53	------	------	------	------	246	5.0	324
			5- 9-56	53	------	------	536	131	360	5.2	296
			6- 3-56	52	------	------	------	------	------	------	------
			9-11-57	53	28	0.17	505	112	381	9.0	370
-15cbd	29.6	I	9-17-55	------	23	------	313	59	161	4.9	282
			3- 8-56	------	------	------	------	------	------	------	------
			5-16-56	56	------	------	488	107	260	5.2	278
			6- 2-56	------	------	------	------	------	------	------	------
-15ccd	38.8	I	11-17-54	------	------	------	416	102	235	7.4	273
			9-17-55	------	22	------	285	72	183	5.1	297
			6- 2-56	54	------	------	------	------	------	------	------
-15cdc1	40	S	11-17-54	------	------	------	392	92	219	6.4	283
			9-17-55	57	21	------	230	61	233	4.7	282
			11-12-55	------	------	------	------	------	------	------	------
			3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
-15dcb	38.0	I	9-17-55	55	20	------	118	23	96	3.3	386
			11-12-55	------	------	------	------	------	------	------	------
			3- 7-56	------	------	------	------	------	114	------	446
			6- 2-56	55	------	------	------	------	------	------	------
-16acb	40.3	I	9-21-55	54	24	------	140	33	73	3.2	288
			3-12-56	53	------	------	------	------	------	------	------
			6- 3-56	53	------	------	------	------	------	------	------
-16bdd1	43	I	9-21-55	53	24	------	143	38	75	3.1	284
			6- 3-56	------	------	------	------	------	------	------	------
			9-11-57	54	------	------	------	------	98	3.4	316
-16bdd3	42.5	I	9-21-55	55	22	------	131	28	73	3.4	280
			3-12-56	------	------	------	------	------	------	------	------
-16ccd2	48.6	I	9-10-55	55	------	------	------	------	------	------	------
			3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-16cdc	44.2	I	9-17-55	54	23	------	132	29	71	3.7	320
			3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	54	------	------	------	------	------	------	------
			9-11-57	53	25	.00	143	28	79	3.4	288
-16ddd1	38.8	I	9-17-55	55	25	------	203	49	105	4.0	292
			11-12-55	56	------	------	------	------	126	4.8	298
			3- 7-56	------	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-16ddd2	36.6	I	3- 7-56	------	------	------	------	------	------	------	------
			6- 2-56	54	------	------	------	------	------	------	------
-20aba	10.6	In	9-21-55	------	------	------	------	------	------	------	------
-20abb	17	In	9-21-55	60	------	------	------	------	------	------	------
-20bda	21.1	In	9-21-55	60	------	------	------	------	------	------	------
-20cbd	([3])	In	10- 6-55	58	24	------	174	26	89	5.3	289
			9-11-57	56	------	------	------	------	92	4.5	296
-20cca [3]	([3])	In	10- 6-55	------	21	------	191	25	97	5.3	455
-20daa	46.1	I	9-21-55	56	------	------	------	------	------	------	------
			3-10-56	53	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-20dab	18.2	I	9- 9-55	55	------	------	------	------	------	------	------
-20dbd	50	In, D	9-10-55	------	------	------	------	------	------	------	------
-20dcb	41.2	I	9-21-55	55	------	------	------	------	------	------	------
-20ddd	37.9	I	9-21-55	56	------	------	------	------	------	------	------
			3-10-56	53	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-21add	52.7	I	9-17-55	55	22	------	109	30	63	3.2	252
			3- 9-56	54	------	------	------	------	------	------	------
			6- 2-56	54	------	------	------	------	------	------	------
			9-11-57	56	25	.00	120	25	72	3.4	244
-21bcc	47.1	I	3-10-56	------	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-21bcd	50	I	3-10-56	53	------	------	------	------	------	------	------
			6- 2-56	56	------	------	------	------	------	------	------
-21bdc1	49.4	I	9-17-55	------	------	------	------	------	------	------	------
			3-10-56	53	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------
-21bdc2	93	I	9-17-55	------	------	------	------	------	------	------	------
			6- 2-56	56	------	------	------	------	------	------	------
-21bdd	97.0	I	9-17-55	55	22	------	117	20	58	3.5	248
			3- 9-56	54	------	------	------	------	------	------	------
			6- 2-56	55	------	------	------	------	------	------	------

See footnotes at end of table.

from the valley-fill deposits—Continued

observation well of U.S. Geol. Survey; S, stock. Results in parts per million except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C.)	pH
					Calculated	Residue on evaporation at 180° C.						
305	878	0.8	19	0.27	2,090	2,440	1,310	1,040	28	2.8	3,590	7.2
315	1,090	1.2	15	----	----	2,600	1,630	1,360	25	2.7	4,240	7.3
399	1,400	----	26	----	----	----	1,880	1,630	29	3.6	5,130	7.1
----	1,160	----	----	----	----	----	----	----	----	----	4,470	----
339	1,300	1.1	16	.26	2,870	3,470	1,720	1,420	32	4.0	4,890	7.3
193	660	.8	18	.19	1,570	1,890	1,020	789	25	2.2	2,810	7.3
----	1,120	----	----	----	----	----	----	----	----	----	4.240	----
259	1,200	----	13	----	----	----	1,660	1,430	25	2.8	4,360	7.3
----	1,100	----	----	----	----	----	----	----	----	----	4,100	----
304	1,010	.8	18	.52	----	----	1,460	1,230	26	2.7	3,880	7.3
228	656	.8	31	.24	1,630	1,870	1,010	766	28	2.5	2,830	7.4
----	1,960	----	----	----	----	----	----	----	----	----	6,620	----
472	760	1.2	16	.29	----	----	1,360	1,120	26	2.6	3,430	7.4
183	640	.8	9.9	.20	1,520	1,730	824	593	38	3.5	2,740	7.5
----	728	----	----	----	----	----	----	----	----	----	3,110	----
----	992	----	----	----	----	----	----	----	----	----	4,040	----
----	1,760	----	----	----	----	----	----	----	----	----	6,120	----
148	82	1.2	18	.24	----	720	388	71	35	2.1	1,140	7.4
----	96	----	----	----	----	----	----	----	----	----	1,130	----
147	111	----	----	----	----	----	415	49	37	2.4	1,260	7.5
----	114	----	----	----	----	----	----	----	----	----	1,370	----
198	140	1.0	11	.16	----	813	486	250	24	1.4	1,240	7.4
----	142	----	----	----	----	----	----	----	----	----	1,260	----
----	142	----	----	----	----	----	----	----	----	----	1,230	----
230	136	1.0	14	.16	----	855	512	279	24	1.4	1,300	7.5
----	146	----	----	----	----	----	----	----	----	----	1,180	----
----	173	----	----	----	----	----	740	481	22	1.6	1,690	8.1
200	114	.8	16	.11	----	770	444	214	26	1.5	1,170	7.4
----	126	----	----	----	----	----	----	----	----	----	1,230	----
----	64	----	----	----	----	----	----	----	----	----	1,030	----
----	58	----	----	----	----	----	----	----	----	----	985	----
----	52	----	----	----	----	----	----	----	----	----	958	----
188	94	.6	18	.08	----	757	448	186	25	1.5	1,160	7.8
----	67	----	----	----	----	----	----	----	----	----	1,100	----
----	76	----	----	----	----	----	----	----	----	----	1,070	----
162	160	.7	17	.13	----	819	472	236	27	1.6	1,250	7.7
140	380	.8	15	.20	1,070	1.260	708	469	24	1.7	1,910	7.7
150	574	.6	16	----	----	1,500	948	704	22	1.8	2,480	7.3
----	275	----	----	----	----	----	----	----	----	----	1,520	----
----	320	----	----	----	----	----	----	----	----	----	1,620	----
----	231	----	----	----	----	----	----	----	----	----	1,340	----
----	260	----	----	----	----	----	----	----	----	----	1,460	----
----	----	----	----	----	----	----	----	----	----	----	1,040	----
----	89	----	----	----	----	----	----	----	----	----	1,320	----
----	104	----	----	----	----	----	----	----	----	----	1,360	----
338	89	.8	33	.11	----	963	540	303	26	1.7	1,370	7.4
----	92	----	----	----	----	----	508	265	28	1.8	1,300	8.1
300	84	.8	.1	.08	----	986	580	207	26	1.8	1,430	7.5
----	85	----	----	----	----	----	----	----	----	----	1,160	----
----	56	----	----	----	----	----	----	----	----	----	878	----
----	58	----	----	----	----	----	----	----	----	----	926	----
----	86	----	----	----	----	----	----	----	----	----	1,480	----
----	86	----	----	----	----	----	----	----	----	----	1,270	----
----	86	----	----	----	----	----	----	----	----	----	1,340	----
----	70	----	----	----	----	----	----	----	----	----	1,220	----
----	77	----	----	----	----	----	----	----	----	----	1,310	----
----	76	----	----	----	----	----	----	----	----	----	1,300	----
74	175	.6	4.3	.10	----	689	396	189	26	1.4	1,100	7.7
----	196	----	----	----	----	----	----	----	----	----	1,130	----
----	202	----	----	----	----	----	----	----	----	----	1,150	----
65	208	1.1	1.8	.12	----	726	404	204	28	1.6	1,140	7.8
----	59	----	----	----	----	----	----	----	----	----	884	----
----	54	----	----	----	----	----	----	----	----	----	875	----
----	47	----	----	----	----	----	----	----	----	----	864	----
----	44	----	----	----	----	----	----	----	----	----	855	----
----	41	----	----	----	----	----	----	----	----	----	825	----
----	45	----	----	----	----	----	----	----	----	----	867	----
----	44	----	----	----	----	----	----	----	----	----	880	----
----	42	----	----	----	----	----	----	----	----	----	824	----
----	54	----	----	----	----	----	----	----	----	----	830	----
215	52	.6	16	.06	----	657	376	173	25	1.3	964	7.9
----	71	----	----	----	----	----	----	----	----	----	1,100	----
----	64	----	----	----	----	----	----	----	----	----	1,050	----

TABLE 8.—*Chemical analyses of water*

[D, domestic; I, irrigation; In, industrial; Iu, irrigation (unused); M, municipal; N, none; O–GS

Well	Well depth (feet)	Use	Date of collection	Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
C2-67-22bab	45	D, S	9-17-55	54	------	------	------	------	------	------	------
			11-12-55	54	------	------	------	------	232	4.6	328
			3- 7-56	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
-22bcb	47.1	I	9-17-55	55	22	------	196	48	96	4.2	261
			11-12-55	54	------	------	------	------	77	3.4	246
			3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	54	------	------	------	------	------	------	------
-22bcc1	47.6	I	9-20-55	55	21	------	255	62	107	4.4	220
			11- 8-55	------	20	------	285	67	114	4.6	220
			11- 9-55	54	21	------	248	56	107	4.5	224
			5- 9-56	55	------	------	264	70	154	4.2	220
			6- 2-56	55	------	------	------	------	------	------	------
-22bcc2	45.7	I	9-20-55	55	22	------	378	100	138	5.1	200
			6- 2-56	52	------	------	------	------	------	------	------
-22bcc3	38.3	I	3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
-22caa	50.7	I	9-20-55	55	21	------	984	355	1,300	11	182
			11-12-55	------	------	------	------	------	------	------	------
			3- 7-56	------	------	------	------	------	------	------	------
			6- 2-56	54	------	------	------	------	------	------	------
-22cbc	36.5	N	11- 9-55	54	------	------	------	------	------	------	------
			3- 8-56	55	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
22cca	42.1	N	3- 8-56	------	------	------	------	------	------	------	------
			6- 2-56	62	------	------	------	------	------	------	------
-28aaa	------	D, I	9-20-55	------	27	------	113	23	73	3.9	238
			11-12-55	------	------	------	------	------	------	------	------
			3- 7-56	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
			9-11-57	56	------	------	------	------	84	4.3	224
-28abc	50	D	9-21-55	------	------	------	------	------	------	------	------
			11-12-55	------	------	------	------	------	------	------	------
			3-10-56	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
-28bbb	44.1	I	9-20-55	------	------	------	------	------	------	------	------
-28dbbl	30	I	9-20-55	56	24	------	91	13	53	3.3	272
			11-12-55	------	------	------	------	------	------	------	------
			6- 2-56	------	------	------	------	------	------	------	------
			9-11-57	55	------	------	------	------	56	3.5	268
-28dbb2	50	D	3-10-56	------	------	------	------	------	------	------	------
-29dcdl	63.3	I	9-21-55	56	------	------	------	------	------	------	------
-32aa1	64	D, S	11-17-54	------	------	------	187	22	79	6.6	250
C2-68-35cbb	------	I	9-12-57	------	21	0.61	260	22	478	2.7	492
C3-66-4bcc	42.6	I	10- 7-55	57	27	------	83	30	68	4.4	336
-9bbc	32	I	10- 7-55	55	31	------	120	27	88	3.0	320
-17bdc	50	I	10- 5-55	------	24	------	51	9.2	36	3.0	184
C3-67-7dba [3]	------	S	9-11-57	56	23	.27	115	21	135	7.6	414
-13bbbl	75	D	10- 7-55	------	12	------	74	11	36	4.7	210
-14aca	51	I	10- 6-55	55	26	------	110	12	50	3.8	292
C3-68-2ccc	13.0	I	9-12-57	------	------	------	------	------	91	6.3	342

[1] Includes equivalent of 2 ppm carbonate (CO_3).
[2] Strong odor of gasoline in water.
[3] Spring.

The relation of specific conductance to the concentration of dissolved solids for the water from the valley-fill deposits is shown in figure 20. Only one point was plotted for any given well. Line *A* shows the relation for water in which concentrations, in equivalents per million of sulfate equal or exceed those of chloride, and line *B* shows the relation for water in which concentrations, in equivalents per million, of chloride exceed those of sulfate. Line *B* represents the water in secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W., and line *A* repre-

from the valley-fill deposits—Continued

observation well of U.S. Geol. Survey; S, stock. Results in parts per million except as indicated]

Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25° C.)	pH
					Calculated	Residue on evaporation at 180° C.						
--------	510	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,390	----
475	640	0.8	14	--------	--------	2,140	1,160	891	30	3.0	3,160	7.3
--------	1,000	--------	--------	--------	--------	--------	--------	--------	--------	--------	4,150	----
--------	1,600	--------	--------	--------	--------	--------	--------	--------	--------	--------	5,800	----
125	400	.6	9.5	0.13	1,030	1,270	686	472	23	1.6	1,840	7.5
86	249	.6	6.0	--------	--------	862	484	282	26	1.5	1,360	7.5
--------	335	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,610	----
--------	680	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,840	----
100	586	.6	9.4	.10	1,250	1,510	892	712	21	1.6	2,360	7.7
108	674	.6	12	.10	1,390	1,560	988	808	20	1.6	2,640	7.3
101	552	.4	12	.10	1,210	1,460	848	664	21	1.6	2,250	7.5
104	710	--------	17	--------	--------	--------	946	766	26	2.2	2,710	7.4
--------	660	--------	--------	--------	--------	--------	--------	--------	--------	--------	2,590	----
135	944	.4	13	.12	1,830	2,140	1,360	1,200	18	1.6	3,440	7.6
--------	1,580	--------	--------	--------	--------	--------	--------	--------	--------	--------	5,280	----
--------	1,660	--------	--------	--------	--------	--------	--------	--------	--------	--------	5,640	----
--------	1,740	--------	--------	--------	--------	--------	--------	--------	--------	--------	5,710	----
579	4,250	.8	10	.25	7,600	8,380	3,910	3,760	42	6.6	12,800	7.2
--------	4,290	--------	--------	--------	--------	--------	--------	--------	--------	--------	13,100	----
--------	4,230	--------	--------	--------	--------	--------	--------	--------	--------	--------	12,800	----
--------	4,000	--------	--------	--------	--------	--------	--------	--------	--------	--------	12,100	----
--------	178	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,080	----
--------	208	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,160	----
--------	220	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,140	----
--------	1,060	--------	--------	--------	--------	--------	--------	--------	--------	--------	3,810	----
--------	1,120	--------	--------	--------	--------	--------	--------	--------	--------	--------	3,970	----
74	191	.4	1.1	.08	--------	772	378	183	29	1.6	1,130	8.0
--------	204	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,190	----
--------	217	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,200	----
--------	220	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,220	----
--------	198	--------	--------	--------	--------	--------	368	184	33	1.9	1,110	8.0
--------	38	--------	--------	--------	--------	--------	--------	--------	--------	--------	787	----
--------	42	--------	--------	--------	--------	--------	--------	--------	--------	--------	826	----
--------	39	--------	--------	--------	--------	--------	--------	--------	--------	--------	838	----
--------	42	--------	--------	--------	--------	--------	--------	--------	--------	--------	878	----
--------	47	--------	--------	--------	--------	--------	--------	--------	--------	--------	805	----
112	36	.6	17	.07	--------	496	282	59	29	1.4	771	8.0
--------	36	--------	--------	--------	--------	--------	--------	--------	--------	--------	777	----
--------	38	--------	--------	--------	--------	--------	--------	--------	--------	--------	803	----
--------	40	--------	--------	--------	--------	--------	303	83	28	1.4	802	7.9
--------	38	--------	--------	--------	--------	--------	--------	--------	--------	--------	776	----
--------	68	--------	--------	--------	--------	--------	--------	--------	--------	--------	1,180	----
383	70	.5	25	--------	--------	--------	557	352	23	1.5	1,300	7.7
1,240	40	.4	59	.12	2,370	2,510	738	335	58	7.7	3,050	8.0
102	52	1.2	38	.17	--------	581	330	54	31	1.6	921	7.5
221	71	1.0	24	.12	--------	775	410	148	32	1.9	1,150	7.7
48	26	1.0	8.3	.06	--------	302	165	14	32	1.2	486	7.8
187	92	.6	8.2	.28	--------	802	374	35	43	3.0	1,240	7.8
96	28	.1	11	.01	--------	389	228	56	25	1.0	618	7.7
116	43	.4	28	.03	--------	548	323	84	25	1.2	842	7.8
--------	--------	--------	--------	--------	--------	--------	433	152	31	1.9	1,160	7.6

sents the water in the rest of the report area. Figure 20 can be used to estimate fairly accurately the dissolved-solids concentration in the samples in table 8 for which the concentration was not determined.

The relation of concentrations of principal constituents to specific conductance is shown in figures 21 and 22. The results of only one analysis were plotted for any given well. Because of the large number of analyses available for samples having conductances between 1,000 and 2,000 micromhos per cm, many of the points in the figures, especially for chloride, are not shown discretely.

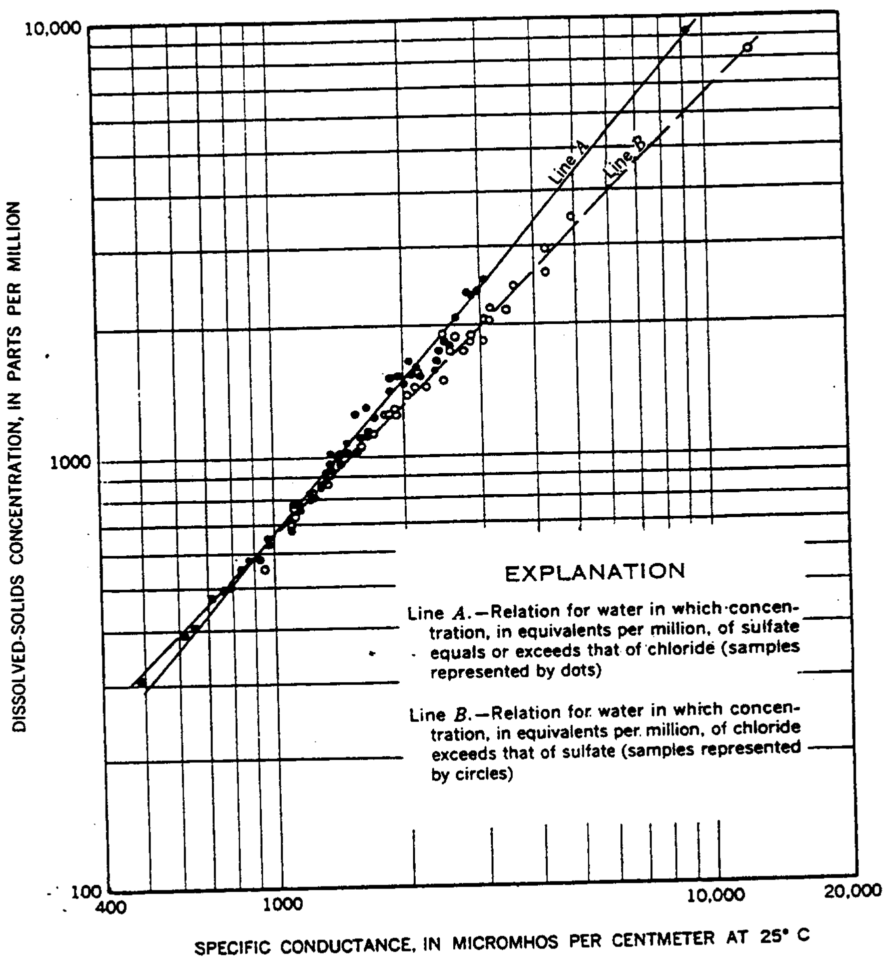

Figure 20.—Relation of specific conductance to concentration of dissolved solids for water from the valley-fill deposits.

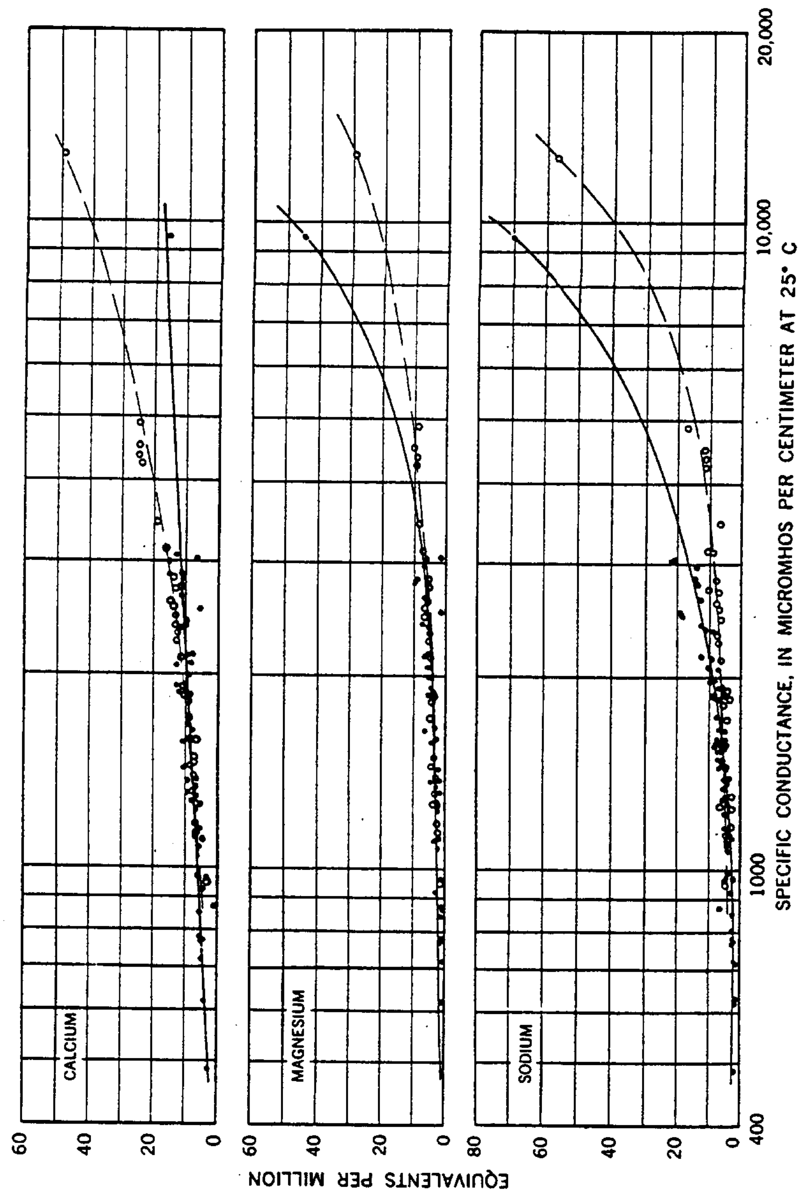

FIGURE 21.—Relation of specific conductance to concentrations of principal cations for water from the valley-fill deposits. Circles represent samples from secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W., where sampling density was high.

695-928 O—64——7

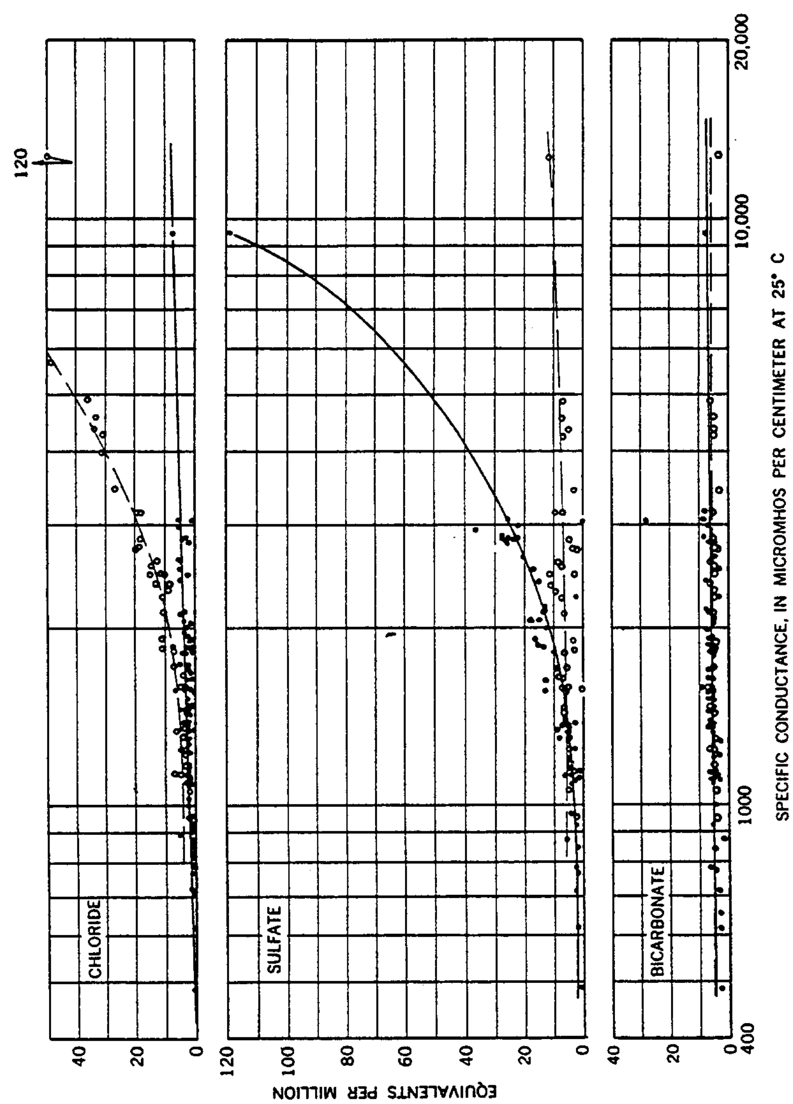

FIGURE 22.—Relation of specific conductance to concentrations of principal anions for water from the valley-fill deposits. Circle represent samples from secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W., where sampling density was high.

The principal curves (solid lines) in figure 21, representing water from nearly all the report area, indicate the following: Calcium is the predominant cation in water having a specific conductance of less than about 2,000 micromhos per cm, whereas sodium is the predominant cation in water having specific conductance of more than about 2,000 micromhos per cm. The concentration of magnesium generally is about half as high as that of calcium in water having a specific conductance of less than about 3,000 micromhos per cm. As the specific conductance increases the concentrations of calcium, magnesium, and sodium increase.

The principal curves (solid lines) in figure 22, also representing water from nearly all the report area, indicate the following: Bicarbonate is the predominant anion in water having a specific conductance of less than 1,000 micromhos per cm. The concentrations of bicarbonate and of sulfate are about equal in water having a specific conductance of about 1,000–1,500 micromhos per cm. Sulfate is the predominant anion in water having a specific conductance of more than about 1,500 micromhos per cm. As the specific conductance increases, the concentration of sulfate increases greatly, the concentration of chloride increases slightly, and the concentration of bicarbonate remains nearly constant.

The figures indicate, therefore, that water from most of the report area having a specific conductance of less than 1,000 micromhos per cm tends to be of the calcium bicarbonate type, that water having a specific conductance of 1,000–2,000 micromhos per cm tends to be of the calcium bicarbonate sulfate type, and that water having a specific conductance of more than 2,000 micromhos per cm tends to be of the sodium sulfate type.

Waste products from settling ponds on the grounds of the Rocky Mountain Arsenal have infiltrated and contaminated the alluvial aquifer in an area of a few square miles in the vicinity of Hazeltine. Comparison of the dashed curves with the principal curves in figures 21 and 22 shows how much the water in secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W., differs from that elsewhere in the report area. The concentrations of calcium are higher than those for water in most of the report area, and the concentrations of sodium generally are lower. The source of contamination was eliminated by constructing an asphalt-membrane lined pond. The extent of contamination is described by Petri and Smith (1959).

The specific conductance of water from the valley-fill deposits is shown on plate 10. Arbitrary ranges in specific conductance were chosen to show relatively small but significant differences in the degree of mineralization of the water, especially in the main river valley.

Specific conductances range from 1,000 to 1,800 micromhos per cm in most of the report area. Conductances of less than 1,000 micromhos per cm were measured mostly near the southern boundary; those of 2,260–4,000 micromhos per cm, in many parts of the report area; and those of more than 4,000 micromhos per cm, only in the vicinities of Derby (T. 2 S., R. 67 W.) and Gill (T. 6 N., R. 64 W.). The water having the lowest specific conductance is in the extreme southern and southeastern parts of the area where surface water is not used extensively for irrigation.

The specific conductance of the ground water in the valley-fill deposits in the main river valley tends to increase in the downvalley direction. In the southwestern part of the valley the specific conductance is about 1,200–1,400 micromhos per cm, whereas in the northeastern part it is about 1,800–2,800 micromhos per cm. The increase is not constant but rather is a series of alternating increases and decreases—the net effect being an increase. The peculiarity in the pattern of the mineralization probably is related to the locations of the diversions from the river. Ground water just downgradient from some of the principal diversions tends to be less highly mineralized than water farther downgradient.

The specific conductance of ground water from nearly all the principal tributary valleys is much higher than that from most of the main valley. However, the specific conductance of a single sample (B4–67–12cdd) indicates that ground water in the Big Thompson River valley may be an exception.

The water is classified in this report as to chemical type according to the cation and anion present in the water in the highest concentrations in equivalents per million. For example, water is said to be of the calcium sulfate type if the concentration of calcium is higher than the concentration of any other cation and the concentration of sulfate is higher than the concentration of any other anion. The chemical type of water in the valley-fill deposits is shown in figure 23, and the areas in which water of given chemical type predominate have been delineated. If the type of water could not be determined directly from the chemical analysis, it was inferred from the relations shown in figures 21 and 22.

Contamination of water by petroleum products was reported by several well owners in the Sand Creek valley near Denver. The strong odor of gasoline in the water from well C3–67–7dba indicates that the water in the valley is contaminated. The odor of gasoline in the water from a spring (C2–67–20cca) at the State Fish Hatchery indicates that the water in the main valley also is affected.

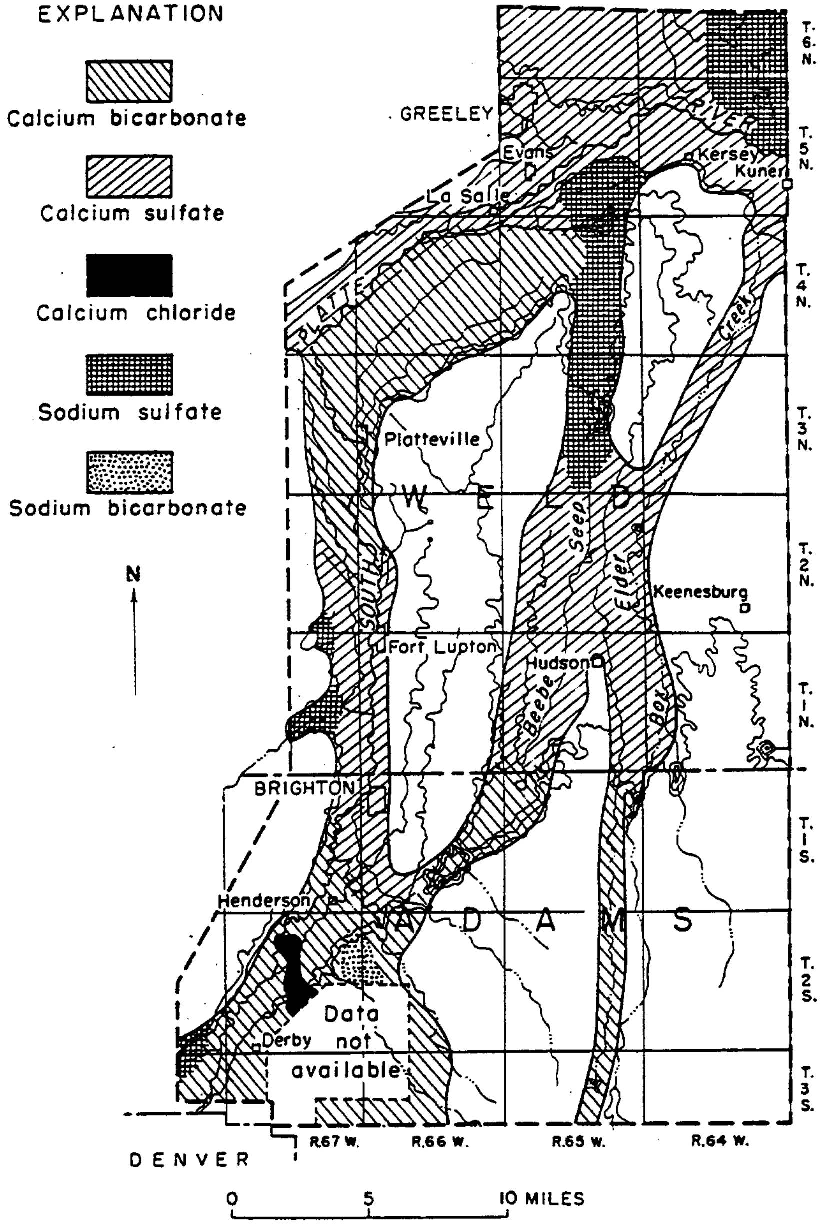

FIGURE 23.—Chemical types of water in the valley-fill deposits.

RELATION OF CHEMICAL COMPOSITION OF WATER IN THE VALLEY-FILL DEPOSITS AND IN THE STREAMS

The chemical composition of the surface waters in the report area has been studied by the U.S. Geological Survey for about 10 years. Results of chemical analyses are published in the annual series of water-supply papers by the Geological Survey entitled "The Quality

of Surface Waters of the United States," parts 5 and 6. Averages of the analyses are given in table 9 of this paper. Most of the averages are arithmetic, but some are discharge weighted. Discharge-weighted averages represent approximately the chemical character of the water if all the water passing a point in the stream during the year were impounded and mixed in a reservoir. Because the averages are calculated in different ways and because the records available are for different years, the data for the different stations are only approximately comparable.

Data in table 10 and plate 10 indicate similarities in the quality of water in the valley-fill deposits and in the streams. For both ground and surface waters, an increase in specific conductance, which is about twofold between Denver and Kersey, is caused principally by increases in concentrations of calcium, magnesium, sodium, and sulfate. Also, the specific conductances of the water in the tributaries are generally higher than those in the main stream, just as specific conductances of the ground water in tributary valleys are generally higher than those in the main valley. The similarities indicate a close relation between the ground and surface waters.

WATER FROM THE BEDROCK

The chemical analyses of water from several stratigraphic units of the bedrock are shown in table 10. Only one or two analyses were made of water from any one unit. The quality of water from any given well may differ widely from the average quality in the unit because the composition of the material composing the unit may differ locally or because the water in the well may be a mixture from two or more units.

The analyses indicate that water from the Dawson arkose and from the Arapahoe formation is the least mineralized of the water sampled and is of the sodium bicarbonate type. Recent data obtained by G. H. Chase (written communication) 1958, however, indicate that water in the Arapahoe formation in many parts of the report area is more mineralized than the water in the two wells sampled and generally is more mineralized than water in the Dawson arkose. The Dawson arkose and the Arapahoe formation are intertongued in some parts of the report area, and the low mineralization in water from the two wells in the Arapahoe may be the result of inflow from the Dawson arkose.

Water in the Laramie formation differs widely in mineralization and in chemical composition from one lithologic unit to another; the specific conductance of samples from the various units ranged from 856 to 5,040 micromhos per cm. Water in the B sandstone of the Laramie formation probably is of better and more uniform quality than the two analyses would indicate; highly mineralized water from coal and ferruginous clay deposits above and below the B sandstone may be entering the two wells sampled.

TABLE 9.—*Averages of chemical analysis of water from streams in the report area*

[Results in parts per million except as indicated]

Period of sampling	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Residue on evaporation at 180°C.	Dissolved solids: Tons per acre-foot	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos at 25°C.)
South Platte River at Henderson																			
Oct. 1955–Sept. 1956 [1]	14	0.03	51	12	67	5.1	147	108	56	0.6	12	-----	413	0.56	176	55	44	2.2	658
South Platte River at Fort Lupton																			
Jan. 1950–Sept. 1955 [2]	16	0.07	86	24	114		266	204	77	1.0	6.8	0.24	700	0.95	303	82	44	2.9	1,040
South Platte River at Kersey																			
Apr. 1947–Sept. 1950 [2]	19	0.03	128	61	130		270	537	41	1.0	8.8	0.21	1,070	1.46	569	346	33	2.4	1,440
Oct. 1950–Sept. 1951 [1]	14	.05	114	47	101	5.6	241	437	34	.7	7.1	.20	917	1.25	478	280	31	2.0	1,250
Oct. 1951–Sept. 1952 [1]	-----	-----	-----	-----	91	-----	227	385	27	-----	-----	-----	849	1.15	433	262	31	1.9	1,130
Oct. 1952–Sept. 1953 [1]	-----	-----	-----	-----	134	-----	338	580	42	-----	-----	-----	1,260	1.71	646	369	31	2.3	1,620
Aug. 1954–Sept. 1956 [2]	16	-----	150	68	141		329	601	38	1.0	7.0	.27	1,270	1.73	657	386	30	2.3	1,640
Clear Creek at mouth near Derby																			
Sept. and Nov. 1955 [3]	12	0.03	56	16	63	4.0	178	165	14	0.7	10	0.11	445	0.61	203	57	40	1.9	664
St. Vrain Creek at mouth near Platteville																			
Jan. 1950–Sept. 1956 [2]	13	0.11	116	83	153		328	596	26	1.2	7.3	0.31	1,240	1.71	631	350	33	2.5	1,590
Big Thompson River at mouth near La Salle																			
Jan. 1950–July 1956 [2]	13	0.06	189	120	196		332	1,040	25	0.9	6.7	0.39	1,880	2.58	996	718	29	2.5	2,270
Cache la Poudre River near Greeley																			
Jan. 1950–Aug. 1956 [2]	17	0.21	183	84	141		402	696	27	0.8	7.1	0.32	1,420	1.94	803	474	26	2.0	1,820

[1] Discharge-weighted average for samples collected daily.
[2] Average for samples collected about once each month.
[3] Average for samples collected less than once each month.

TABLE 10.—*Chemical analyses of water from different stratigraphic units of the bedrock*

[Results in parts per million except as indicated]

Well	Well depth (feet)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption ratio	Specific conductance (micromhos) (at 25°C)	pH
Dawson arkose																							
C3-66-17aaa	269	3- 5-58	11	0.07	3.6	0.2	92	0.6	230	0	2.3	14	1.4	0.0	0.04	------	241	10	0	95	13	399	7.8
Dawson arkose(?)																							
C2-66-21ccc	700	10- 7-55	11	------	1.5	0.1	77	0.6	162	10	17	3.0	2.0	0.9	0.01	------	206	4	0	97	17	336	8.8
Arapahoe formation																							
C2-67-21aaa	535	3-10-56	10	------	1.9	0.1	79	0.2	163	18	6.0	2.5	3.2	2.6	0.07	------	204	5	0	97	15	350	9.0
C2-68-25aad2	750	3- 5-58	10	0.05	.6	1.1	79	.6	190	4	13	2.8	1.9	.0	.04	------	214	6	0	96	14	341	8.4
Laramie formation, undifferentiated																							
B3-66-14bba	420	3- 7-58	16	7.6	96	54	291	6.5	846	0	365	18	0.6	0.3	0.44	1,260	1,280	460	0	57	5.9	1,850	7.6
C1-67-3cdc	823	3- 5-58	8.2	4.9	174	21	1,000	6.0	292	0	1,960	362	1.8	1.0	.06	3,680	3,750	522	283	80	19	5,040	7.9

Dawson arkose and upper part of the Laramie formation, (undifferentiated)																						
C2-65-35cdc	248	3-5-58	11	0.15	9.8	1.3	129	1.8	302	0	3.3	37	1.0	0.0	0.04	......	346	30	0	90	10	571	8.2
B sandstone of the Laramie formation																						
B2-65-19ddd	650	3-6-58	17	0.63	373	163	433	7.6	348	0	1,870	252	3.2	2.3	0.65	3,310	3,550	1,600	1,320	37	4.7	4,020	7.9
B2-67-10bbd	400	3-6-58	8.9	.16	4.3	1.8	386	1.9	536	8	353	42	1.4	2.6	.24	1,070	1,080	18	0	98	40	1,680	8.4
Basal part of the Laramie formation																						
B1-66-21bbd	940	3-6-58	11	0.25	1.5	0.1	210	1.1	504	4	3.0	36	1.7	0.1	0.25	......	529	4	0	99	46	856	8.3
Basal part of the Laramie formation and upper part of the Fox Hills sandstone																						
B2-64-26bda	890	3-6-58	11	0.72	2.9	0.7	289	1.5	654	0	3.3	53	3.4	0.1	0.64	......	685	10	0	98	40	1,120	8.2
C2-68-23cbbb2	1,446	1-10-58[1]	11	1.1	1.6	1.0	294	1.0	681	0	2.5	64	3.6	.0	......	......	749	8	0	99	45	1,210	8.2

[1] Aluminum (Al), 11 ppm; Manganese (Mn), 0.00 ppm; Phosphate (PO_4), 0.05 ppm.

Water from most of the bedrock aquifers is of the sodium bicarbonate type, is soft, and has relatively high concentrations of fluoride.

SUITABILITY OF THE GROUND WATER FOR USE

The economical use of water for most purposes depends on the chemical composition of the water. If the chemical composition does not meet the requirements for a particular use, often the water can be treated so that it will meet the requirements.

In this report the water is classified for irrigation and for public-supply and domestic use. The requirements of water quality for industry are so diverse that any attempt to define them and evaluate the water according to them would be beyond the scope of this report. In general, water that is suitable for public supply is suitable for most industrial uses or can be made suitable without prohibitive expense.

IRRIGATION

Generally, water for irrigation should be of such quality that it will not adversely affect the productivity of the land to which it is applied. Certain properties of the water are of principal importance in determining the effect that the water will have on soil productivity. These properties are the mineralization, or total concentration of the dissolved salts, the relative proportion of sodium to calcium and magnesium, the concentration of boron or other elements that might be toxic to plants, and for some water the concentration of bicarbonate in excess of the concentrations of calcium and magnesium.

High total concentrations of dissolved salts in irrigation water tend to cause an increase of salts in the soil solution and may cause the soil to become saline. Because all plants take in water by osmosis, a favorable balance must be maintained between salts within a plant and salts in the soil solution. When the total concentration of salts in the soil solution becomes too high for plants to get an adequate amount of water, or when the concentration of certain salts in the soil solution becomes so high as to be toxic, the growth of the plants is adversely affected. The tendency of irrigation water to cause an accumulation of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard.

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water can adversely affect soil structure. Cations in the soil solution become fixed on the surface of fine soil particles; calcium and magnesium tend to flocculate the particles, but sodium tends to deflocculate them. Flocculation gives the soil looseness, provides good penetration by water and air, and generally gives the soil good tillage properties. Deflocculation pro-

motes packing and prevents free movement of air and water. The adverse effect on soil structure caused by high concentrations of sodium in the irrigation water is called the sodium hazard of water. An index used for predicting the sodium hazard of a water is the sodium-adsorption ratio (SAR), which is defined by the equation

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}$$

where Na^{+}, Ca^{+2}, and Mg^{+2} are in equivalents per million (U.S. Salinity Lab. Staff, 1954, p. 72).

Most of the mineral constituents of water are essential plant nutrients. However, some of these same constituents may if present in sufficiently high concentrations interfere with normal plant nutrition and growth. High concentrations in soil solutions of such constituents as sodium, calcium, magnesium, chloride, sulfate, and bicarbonate have been reported to be associated with toxic reactions in some plants (U.S. Salinity Lab. Staff, 1954, p. 61–63). Boron is essential to the normal growth of all plants, but the concentrations needed are small; when these concentrations are exceeded, injury to the plants may result.

High concentrations of bicarbonate in irrigation water may cause calcium and magnesium carbonates to precipitate in the soil as the water is concentrated by evapotranspiration. Precipitation of calcium and magnesium results in an increase in the proportionate amount of sodium in the water; the effect on the soil is the same as if the sodium hazard of the irrigation water had been high. High bicarbonate concentrations may also cause an increase in the pH of the soil and may eventually lead to a soil condition known as black alkali. The amount of carbonate plus bicarbonate, expressed in equivalents per million, that would remain in solution if all the calcium and magnesium were precipitated as the carbonate is called the residual sodium carbonate of the water (Eaton, 1950, p. 124).

Investigators have suggested several methods for classifying water for irrigation so that the long-term effect on soil productivity can be forecast (Wilcox, 1948; Scofield, 1936; Eaton, 1950; U.S. Salinity Lab. Staff, 1954). According to the method of the U.S. Salinity Laboratory Staff (1954), used in this report, the water is classified first for salinity hazard and sodium hazard, then for boron concentration, and finally for the amount of residual sodium carbonate.

The salinity hazard and sodium hazard of the water are determined from a diagram. (See fig. 24.) Interpretation of the diagram by the U.S. Salinity Laboratory Staff (1954, p. 80) is as follows:

LOW-SALINITY WATER (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching

is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

MEDIUM-SALINITY WATER (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

HIGH-SALINITY WATER (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

VERY HIGH SALINITY WATER (C4) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissues when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

LOW-SODIUM WATER (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

MEDIUM-SODIUM WATER (S2) will present an appreciable sodium hazard in fine-textured soils having high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.

HIGH-SODIUM WATER (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

VERY HIGH SODIUM WATER (S4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity, where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Each class in the diagram includes a wide range in salinity. For a particular water, the relative position of the point within the class should be considered and not the class alone. Water having a specific conductance of 760 micromhos per cm is certainly much better than water having a specific conductance of 2,240 micromhos per cm; nevertheless, both are classed as C3.

The designers of the diagram point out that:

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerances of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality.

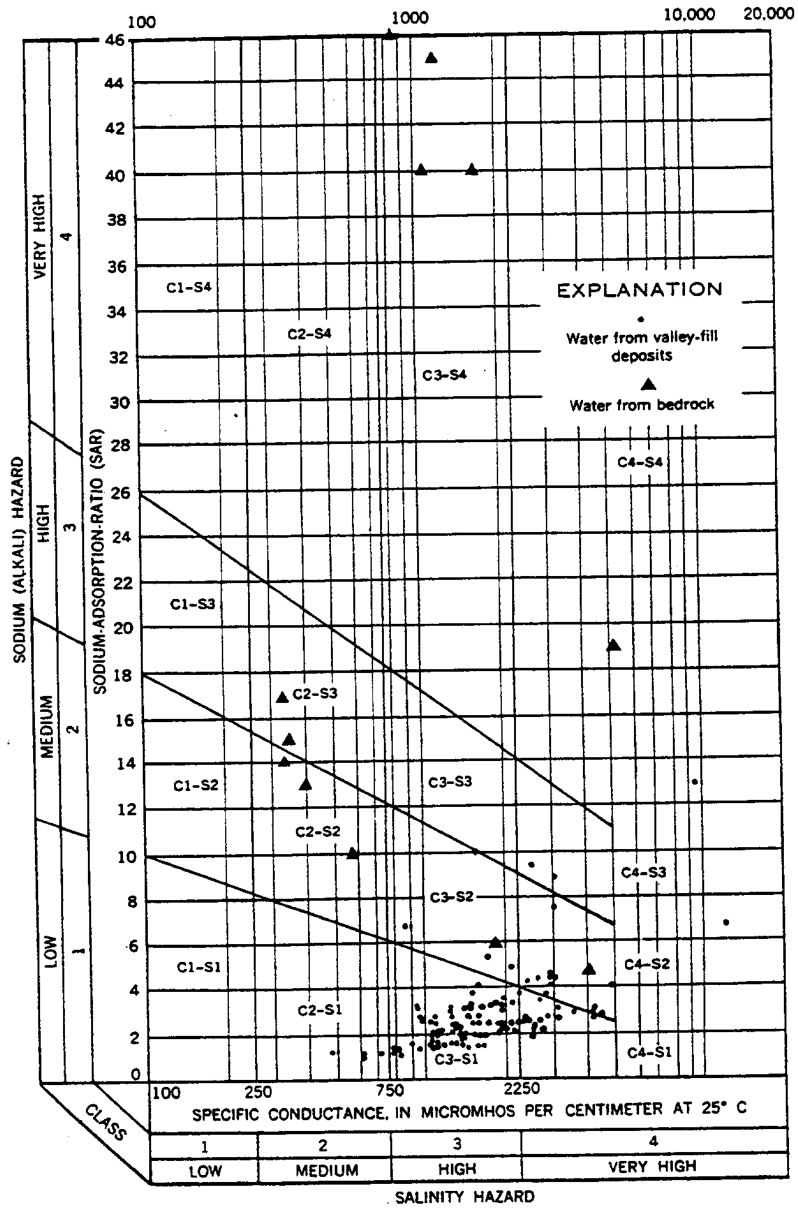

FIGURE 24.—Classification of the water for irrigation (diagram after U.S. Salinity Lab. Staff, 1954).

The water is classified for boron according to the following table (Scofield, 1936, p. 286):

Permissible limits of boron, in parts per million, for several classes of irrigation waters

Boron class	Sensitive crops	Semitolerant crops	Tolerant crops
1	<0.33	<0.67	<1.00
2	.33–.67	.67–1.33	1.00–2.00
3	.67–1.00	1.33–2.00	2.00–3.00
4	1.00–1.25	2.00–2.50	3.00–3.75
5	>1.25	>2.50	>3.75

The effect of the concentration of bicarbonate in irrigation water on the exchangable-sodium percentage of soil has been studied by Wilcox, Blair, and Bower (1954, p. 265). They concluded that water containing more than 2.5 epm of residual sodium carbonate is not suitable for irrigation, that water containing between 1.25 and 2.5 epm is marginal, and that water containing less than 1.25 epm probably is safe.

CLASSIFICATION OF THE WATER

Water from the valley-fill deposits is classified for salinity hazard and sodium hazard in figure 24. Only one point was plotted for a given well. Water from most of the report area has a high or very high salinity hazard and a low sodium hazard.

The concentration of boron in water from the valley-fill deposits ranged from 0.01 to 0.67 ppm. The water from about 80 percent of the wells is of boron class 1 and is suitable for use even on boron-sensitive crops. Water from the remaining 20 percent of the wells is of class 2 for use on boron-sensitive crops and of class 1 for use on boron-tolerant or boron-semitolerant crops. The principal crops grown in the report area, except such fruit crops as peaches, cherries, and apples, are either boron tolerant or boron semitolerant.

The water in the report area, except in the vicinity of one well (C2–67–13cad), contains no residual sodium carbonate and, therefore, is classed as suitable in regard to this property.

Data in table 10 and in figure 24 indicate that water from the stratigraphic units of the bedrock is probably unsuitable for irrigation because of a high salinity hazard, a high sodium hazard, or a high concentration of residual sodium carbonate, or all three.

LEACHING REQUIREMENTS OF WATER FROM THE VALLEY-FILL DEPOSITS

Salts in water that has been applied to the soil gradually become more concentrated because of the loss of water by evaporation and plant use. The accumulation of large amounts of salt in the root zone of the soil profile in irrigated fields causes the soil to become

saline unless sufficient water is applied to leach the salts through the root zone. Eaton (1954, p. 4) gives the following equation for estimating the percentage of the applied water that must pass through the root zone to provide adequate leaching:

$$\frac{Sw \times 100}{(2 \times Mss) - Sw} = d\%$$

in which—

Sw is salinity of irrigation water, in equivalents per million of Cl plus $\frac{1}{2}SO_4$

Mss is salinity of mean soil solution, in equivalents per million of Cl plus $\frac{1}{2}SO_4$

d% is percentage of applied water that should be passed through the root zone (leaching requirement).

The deleterious effects on plant growth of high salinity in the root zone are caused principally by sulfate and chloride. The effects of salinity from sulfate are about half as great as the effects of salinity from chloride when the two are present in equivalent concentrations. The mean soil solution (*Mss*) causing a significant reduction in crop yields varies with soil structure, climatic conditions, and salt tolerance of crops grown. Eaton (1954) assumed that for average conditions the *Mss* should not exceed about 40 epm if reasonable yields (about 70–80 percent of the yield that would normally be expected from nonsaline soils) are to be produced. The assumption is based on observations of crops of intermediate salt tolerance grown in the semiarid climate of Riverside, Calif., and probably is valid for the report area.

The approximate leaching requirements of water from the valley-fill deposits are given in the following table:

Average leaching requirements for ranges of specific conductance

Range of specific conductance (microhms per cm at 25°C)	Leaching requirement, in percent (d%)	
	For water in most of the report area	For water in secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W.
<1,000	<5	<10
1,000–1,400	5–8	10–11
1,410–1,800	8–12	11–14
1,810–2,250	12–17	14–21
2,260–3,000	17–26	21–37
3,010–4,000	26–43	37–74
>4,000	>43	>74

In the calculation of the leaching requirements, an *Mss* of 40 epm was used. Where only such salt tolerant crops as sugar beets and barley are to be irrigated, a concentration higher than 40 epm may be used. Concentrations of Cl plus $\frac{1}{2}SO_4$ were taken directly from the curves in figure 22.

For water from most wells in the irrigated valleys of the report area (pl. 10) the leaching requirement ($d\%$) is less than about 12 and is probably provided by the normal irrigation practices, because the drainage characterstics of the soil profile generally are good. Special farming practices for salinity control may be needed where the $d\%$ is between 12 and 17 and definitely are needed where the $d\%$ is more than 17. The $d\%$ is higher in secs. 9, 10, 15, 16, 22, T. 2 S., R. 67 W., than in most of the report area because the water has proportionately higher concentrations of chloride. The $d\%$ of some of the water is so high that accumulation of salts in the soil probably would be difficult or impossible to prevent even if special practices for salinity control were introduced.

PUBLIC SUPPLY AND DOMESTIC USE

Generally the dissolved mineral constituents of most importance in water for public supply and domestic use are calcium and magnesium, iron and manganese, fluoride, sulfate, chloride, and nitrate. The presence of high concentrations of these constituents may make the water unfit for use because of their physiological effects on human beings or because of esthetic or economic reasons.

Calcium and magnesium in water are the chief cause of hardness, which impairs the quality of the water because of the curd that forms when soap is added and because of scale that is deposited in pipes and in water heaters and boilers. Also, magnesium in high concentrations, especially when associated with sulfate, may act as a laxative.

Iron and manganese in high concentrations stain laundry and fixtures, and they can be tasted in concentrations higher than 0.5–1.0 ppm (California Inst. Technology, 1952, p. 276). Also, high concentrations of iron may promote the growth of iron bacteria, which in turn make water unpalatable.

High concentrations of chloride salts cause water to taste salty and may cause physiological injury to people suffering from certain heart or kidney ailments.

Fluoride in drinking water in concentrations exceeding 3.0 ppm may cause pronounced mottling of the teeth of children and in concentrations exceeding 1.5 ppm may cause noticeable mottling. A small amount of fluoride, however, aids in sound tooth development and lessens the incidence of dental caries. The presence of 0.6–1.5 ppm in drinking water probably satisfies the requirement for sound tooth development (Am. Water Works Assoc., 1950, p. 66–67).

High concentrations of sulfate salts may cause a laxative effect; however, many persons develop a tolerance to the sulfate through continued use of the water. A cathartic dose of sulfate is 1.0–2.0 grams, which is equivalent to a liter of water containing 1,000–2,000 ppm of sulfate (California Inst. Technology, 1952, p. 377–378).

Nitrate is the end product in the oxidation of organic nitrogen compounds; therefore, high concentrations of nitrate may indicate pollution associated with the decomposition of organic wastes. High concentrations of nitrate cause cyanosis in some infants fed with the water.

The U.S. Public Health Service (1946) gives standards for the quality of water for use by interstate carriers subject to Federal quarantine regulations. The standards tend to be conservative because they are designed for the protection of people who are easily affected by changes in water and who have no opportunity to become accustomed to the water. The standards have been adopted by the American Water Works Association as criteria of quality for public supplies. The maximum concentration recommended in the standards for some of the chemical constituents are as follows:

Constituent	*Maximum concentration ppm*
Iron plus manganese (Fe+Mn)	0.3
Magnesium (Mg)	125
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)[1]	1.5
Nitrate (NO_3)[2]	44
Dissolved solids[3]	500

[1] Mandatory.
[2] Maxcy, 1950, p. 265. Not a Public Health Service recommendation.
[3] 1,000 ppm permitted if water of better quality is not available.

No specific standards for hardness have been established, but the following classification of water with respect to hardness is generally recognized.

Hardness (ppm)	Class	Suitability
<60	Soft	Suitable for many uses without further softening.
60–120	Moderately hard	Usable except in some industrial applications.
121–200	Hard	Softening required by laundries and some other industries.
>200	Very hard	Softening required for many uses.

Water from the valley-fill deposits in most of the report area is of poor quality for public-supply and domestic use. It is highly mineralized, is very hard, and has high concentrations of sulfate. Fluoride concentrations in much of the report area are slightly in excess of the maximum allowable concentration. The concentrations of iron, magnesium, chloride, and nitrate are low in most places, but the concentrations of chloride in some water in the vicinity of Derby are very

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high. Calculations of the Langelier calcium carbonate saturation index, which is a measure of the tendency of water to deposit scale or to attack metals corrosively (Powell, 1954, p. 276–282), indicate that water from the valley-fill deposits has a tendency toward scale formation.

Water from the Dawson arkose, the Arapahoe formation, and the upper part of the Laramie formation probably is of good quality for public supply and domestic use except for high concentrations of fluoride. It is only lightly mineralized, is soft, and has low concentrations of iron, magnesium, sulfate, chloride, and nitrate. Calculations of the Langelier index indicate that some of the water in these stratigraphic units is slightly corrosive. In the basal part and in some other parts of the Laramie formation the water probably is of fair quality for public and domestic use, but in some parts it is of very poor quality. In the B sandstone of the Laramie formation the water may be of fair or even good quality for public supply and domestic use at most places, although the two analyses in table 10 indicate that the water is of poor quality. Analyses of mixtures of water from the basal part of the Laramie and from the upper part of the Fox Hills sandstone indicate that water from the Fox Hills is at least of fair quality for public supply and domestic use though it might have relatively high concentrations of fluoride.

GROUND-WATER CONDITIONS AND UTILIZATION IN THE VALLEYS

The valleys in the report area are here divided into five districts based on drainage, geohydrology, availability, and utilization of ground water. This study is concerned primarily with ground water in the valley-fill deposits, which supply nearly all the wells in the area that have a large capacity. Although many residents of the area obtain water for domestic and stock use from small-capacity wells in the valley-fill deposits, the yields generally are only a few gallons per minute per well and the total pumpage from these wells in each district is negligible. Therefore, the small-capacity wells are not included in the discussion of the districts.

Small-capacity wells that produce water for domestic, stock, industrial, and municipal use have been drilled into the bedrock formations throughout the report area, on both the uplands and in the valleys. They generally produce a few gallons of water per minute from aquifers in the Denver and Arapahoe formations, the Dawson arkose, and the Laramie formation, and some obtain water from the Fox Hills sandstone. Around the turn of the century, water flowed at the land surface from many of these wells, but artesian pressures have declined steadily in most places with the result that most of the artesian wells no longer flow; although many that no longer flow are

pumped, some have been abandoned. Because the wells in the bedrock formations generally do not produce ground water suitable in quantity and quality for irrigation use and because the combined pumpage from these wells is relatively small, they are not discussed in the description of the districts.

Water that issues from springs on terrace scarps along the east side of the river flood plain in the South Platte River valley is used by several fish hatcheries and for stock watering. Springs issue at many places along the channel of Beebe Seep and help to sustain the flow of the seep.

For more detailed data on the districts, the reader is referred to the well records and logs Basic-Data Report No. 9 (Schneider, 1962), and to the tables, maps, and other illustrations in this report.

SOUTH PLATTE RIVER VALLEY

DENVER TO THE BASE LINE

In this district, the South Platte River valley trends northeastward and the river follows a course along the northwestern side of the valley. In the downstream direction, the main valley is joined successively by the valleys of Sand, Clear, First, Second, and Third Creeks. The upland on the east side of the main valley is drained by First, Second, and Third Creeks and that on the west side is drained by ephemeral streams that enter the report area. Bedrock forms the rather steep west wall of the river valley; the gently rolling surface of the older terrace which slopes upward to the rolling divide forms the eastern side of the valley. The flattest parts of the floor of the main valley are composed of the river flood plain and the Kersey and Kuner terraces. Plates 1 and 4 show the ancestral channels of the South Platte River that were eroded in the consolidated rocks; one of the buried channels trends northeastward from the main valley and passes beneath Barr Lake. These ancestral channels are partly filled with the valley-fill deposits that form the principal aquifer in the district. The thickness of the valley fill averages 50 feet along the valley, but along testhole line A–A' in the southeastern part of the district, where the width of the fill is about 11 miles, well C3–67–4bcd and test hole C3–67–3cbb reached a depth of about 100 feet before bedrock was encountered. At a point 3 miles north, well C2–67–21bdd was dug in valley-fill deposits to a depth of 97 feet. The width of the valley fill decreases downstream to about 4½ miles at a bedrock spur in the vicinity of sec. 8, T. 2 S., R. 66 W., and then increases abruptly where Third Creek enters the main valley. At the base line the width is only 2½ miles.

The contours on plate 5 show that the gradient of the water table ranges from about 12 ft per mile under the flood plain of the river to about 31 ft per mile in the terrace deposits. Ground water in the

valley-fill deposits is moving toward the river in a downvalley direction. Spurs and inliers of the bedrock cause the distinct mounds and local steepening in the water table that appear at the extreme southwestern corner of the district and in the area southeast of sec. 22, T. 2 S., R. 67 W. The trough in the water table, which roughly follows the channel of the river, shows that the ground-water reservoir is discharging into the river. In the area southeast of the mouth of Sand Creek, the shape of the water table indicates that much of the recharge to the ground-water reservoir is entering through the valley-fill deposits of Sand Creek. The smaller irregularities in the shape and slope of the water table throughout the district are caused by several factors. They may be due to local differences in the rate of ground-water recharge, such as increments of recharge from tributary valleys, irrigated tracts, canals, and reservoirs, or to discharge by evapotranspiration or heavy local pumping. Many of the irregularities probably are caused by the differences in the thickness and permeability of the sediments and, along the east side of the valley, by the uneven surface of the bedrock.

On the flood plain of the river, the depth to water ranges from 0 in swampy areas to about 10 feet, and on the terraces, the depth to water ranges from 8 to 80 feet (pl. 6). Hydrographs of the water levels in U.S. Geological Survey observation wells in the district (fig. 11) show a normal seasonal rise and decline of the water table, and some monthly fluctuations that are due to irrigation pumping; and they show that the greatest annual change in depth to water during the period November 1955 to May 1958 was about 10 feet in wells C1–66–18cdc and C2–67–11ccd. Hydrographs of the long-term observation wells (fig. 10) show that the most appreciable change in water levels was a lowering during the early 1940's and the early and middle 1950's (periods of drought and heavy pumping). Both the short- and long-term hydrographs show that by 1958 the water levels had recovered almost to their previous recorded average level.

Ground water withdrawn from the valley-fill deposits is used mainly for irrigation. Irrigation wells generally are used to supplement irrigation water diverted from the South Platte River, but in some places wells are the sole source of supply. A well-location map, prepared by Code (1943), shows that in 1940 there were 215 irrigation wells in this district; by the end of 1957 the number had increased to 420. Although the average concentration of irrigation wells in the irrigated part of the valley is about 6 per section, a few sections contain no irrigation wells and many contain several more than 6. The irrigation wells are most concentrated in sec. 35, T. 2 S., R. 68 W., where a total of 28 were inventoried. Most of the irrigation wells in this district were dug to bedrock and are lined with concrete casing;

some were drilled and are lined with metal casing. Turbine pumps are used in most of the wells, but a few centrifugal pumps are in use. Although a few pumps are operated by internal-combustion engines, most are electrically driven.

Brighton (population 6,000) [1] is supplied by one dug well and nine drilled metal-cased wells that obtain water from the valley-fill deposits. The wells are equipped with electrically driven turbine pumps that pump water directly into the city mains and into a 200,000-gallon elevated steel tank, which maintains an average operating pressure of about 55 psi (pounds per square inch) in the city distribution system. The average rate of pumping is about 1,400,000 gpd, which is equivalent to about 1,570 acre-ft per yr.

Thornton (population 10,250) is supplied by five dug wells that obtain water from the valley-fill deposits beneath the flood plain, by one dug well that obtains water from the valley-fill deposits beneath the Kersey terrace, and by two deep drilled wells that obtain water from bedrock aquifers. Electrically driven turbine pumps force the water from the wells directly into the town mains and into a 600,000-gallon surface reservoir and a 75,000-gallon underground reservoir, which maintain pressures ranging from 30 to 90 psi at service outlets. The average rate of pumping is about 2,900,000 gpd, or about 3,250 acre-ft per yr.

The remaining municipalities in the district do not have public water systems, and water is supplied by privately owned wells or by the Denver municipal water system.

Ground water is pumped from the valley-fill deposits by several industries in the district. A sugar refinery at Brighton obtains water from a drilled well for use in washing beets and refining sugar. The well supplies about 450 gpm during the 90-day operating season, or about 200 acre-ft per yr. Some sand and gravel companies and small industries obtain ground water from wells or from large open pits.

The yields of 118 large-capacity wells that were measured by the U.S. Geological Survey ranged from 65 to 1,640 gpm and averaged 400 gpm; drawdowns ranged from 1 to 27 feet, and specific capacities ranged from 15 to 295 gpm per ft of drawdown.

The results of aquifer tests (fig. 16 and table 5) show that high coefficients of permeability and transmissibility generally characterize the valley-fill deposits beneath the flood plain and the Kersey and Kuner terraces. Those wells that have low yields and excessive drawdown probably are poorly constructed or produce from local zones of low permeability. In general, the wells that obtain water from the unconsolidated deposits beneath the highest terrace between

[1] Populations given in this report are 1957 estimates taken from the Colorado Gazetteer of Cities and Towns, Colorado State Planning Division (1958).

Brighton and the southern boundary of the report area, or from the slope-wash deposits that border the river valley, are not as productive as the wells that tap deposits beneath the younger terraces or the flood plain.

The quantity of ground water that is pumped from the large-capacity wells in this district during a year of normal precipitation and pumping is about 40,000 acre-ft. The areal extent and the thickness of saturated valley-fill deposits are shown on plate 8; it was estimated that about 300,000 acre-ft of recoverable ground water was in storage in November 1957. The hydrograph of well C1-67-13dbd (fig. 10) shows a downward trend of the water table during periods of drought but shows also a recovery of the water table during periods of high precipitation and surface runoff. The record from this well suggests that the ground-water reservoir is not being depleted by pumping over a long period of years; that is, the average rate of discharge appears to be balanced by the average rate of recharge. Because the close spacing of wells in many parts of the district has resulted in mutual interference, any additional large-capacity wells drilled in other parts of the district should be spaced so as to minimize aggravating the problem.

Water in the valley-fill deposits in this district is diverse both in degree of mineralization and in chemical type (pl. 10 and fig. 23). In most of the southern part of the district the water has a specific conductance of less than 1,400 micromhos per cm and is of the calcium bicarbonate type, similar to water in the South Platte River. In the northern part of the district the water ranges in specific conductance from 1,410 to 1,800 micromhos per cm and is of the calcium sulfate type. The change in predominance from bicarbonate to sulfate in ground water is caused by the use of the water for irrigation. Because bicarbonate in water used for irrigation generally precipitates as carbonate salts, the relative proportion of sulfate and other anions in the water increases. As the water moves downvalley, the proportion of sulfate and other anions to bicarbonate increases; therefore, the greater the distance from the original source of the irrigation water, the greater the proportion of sulfate and other anions.

The area contaminated by wastes from the Rocky Mountain Arsenal, which was mentioned on page 93, is near the central part of the district. The water is highly mineralized, the principal ions being calcium and chloride. This contaminated body of ground water is gradually moving north-northwestward into the South Platte River. Both the degree of mineralization of water from certain individual wells (C2-67-15 bad, bdal, ccd) and the areal extent of the body of highly mineralized water fluctuate somewhat from season to season and probably from year to year; the chemical quality of the water

in the area through which the highly mineralized water was moving in the 1955–57 period may be considerably modified in succeeding years. A small area where the water is also highly mineralized but is of the sodium bicarbonate type lies in and near the valley of First Creek.

In the southwestern part of the district, some of the ground water entering the South Platte River valley from the Clear Creek valley is of the sodium sulfate type (C2–68–35cbb, table 8), but some, moving at very shallow depth, is of the calcium bicarbonate type (C3–68–2ccc). The sample from well C3–68–2ccc represents recharge from recent local irrigation with surface water, whereas the sample from well C2–68–35cbb probably represents water that entered the ground-water reservoir a considerable distance upvalley. The water in parts of the Sand Creek valley contains much petroleum waste, but the extent and seriousness of contamination are not known.

BASE LINE TO THE NORTHERN BOUNDARY OF T. 3 N.

The river valley trends northward between rolling uplands in this district and the river follows a course down the middle of the valley. Big and Little Dry Creeks and numerous ephemeral streams drain the upland parts of the district. The Fox Hills, Laramie, and Arapahoe formations form the bedrock surface into which the valley was eroded by the ancestral South Platte River (pl. 4). Unconsolidated deposits mantle the surface of the bedrock nearly everywhere and in most of the district they are in direct contact with the Laramie formation. Along the valley, the valley-fill deposits range in thickness from about 40 feet at the base line to about 85 feet at the northern boundary. The width of the fill is about 3 miles in most of the district. Along the eastern side of the main valley and in the valleys of Big and Little Dry Creeks, the Kersey and Kuner terraces are well preserved and form the flat surfaces that border the flood plain. The valley-fill deposits are fringed in many places by slope-wash deposits.

Hydrologic conditions are nearly uniform throughout the district. The gradient of the water table averages about 10 feet per mile and the water-table contours show that the river gains water from the ground-water reservoir. The local flattening of the water table in the vicinity of Fort Lupton and Platteville probably is due to discharge of ground water by the municipal wells, which are pumped throughout the year. The ridge on the water table along the northwestern boundary of the district may be caused by low permeability of the sediments, recharge from irrigation, the bedrock divide between the valleys of the South Platte River and St. Vrain Creek, or a combination of all three factors.

The water table generally is less than 10 feet below the flood plain of the river and 20–40 feet below the higher terrace and the surface

of the slope-wash deposits. Hydrographs of the U.S. Geological Survey observation wells (fig. 12) show that the maximum annual water-level fluctuation was about 6 feet in wells B1–66–20ccd and B2–66–17bbb. The 29-year record of long-term observation well B2–66–20bcc does not show much of a net change in the water level except for an appreciable rise in 1942 (fig. 10). The water level in long-term observation well B1–66–7dd declined during the drought of the late 1930's but otherwise has not fluctuated greatly. The depth to water in both wells was practically the same at the end of the period of record as at the beginning.

The valley-fill deposits contain large quantities of unconfined ground water. Most of the water pumped from wells is used for irrigation. There were 110 irrigation wells in the district in 1940 (Code, 1943), and 345 by the end of 1957. The number of irrigation wells tapping the valley fill ranges from 0 in some sections to as many as 15 in sec. 19, T. 1 N., R. 66 W.; the average concentration is about 5 per section. Most wells are drilled to bedrock, are lined with metal casing, and are equipped with electrically driven turbine pumps, but some are dug and are lined with concrete casing. A few wells are equipped with centrifugal pumps, and a few pumps are driven by internal-combustion engines.

Two municipalities in the district have public water systems that obtain water from wells. Fort Lupton (population 1,900) is supplied by four drilled metal-cased wells that tap valley-fill deposits. The wells are within the city limits and are equipped with electrically driven turbine pumps, which pump water directly into the city mains or into a 100,000-gallon elevated steel tank. An operating pressure of 47–70 psi is maintained in the city distribution system. The average rate of pumping is about 950,000 gpd, or about 1,100 acre-ft. per yr. Platteville (population 570) is supplied with water by a large-capacity drilled well that taps valley-fill deposits and by a small-capacity drilled well that obtains water from the bedrock. About 80,000 gpd, or about 90 acre-ft. per yr., is pumped from the large-capacity well, which is equipped with an electrically driven turbine pump. The pump forces the water directly into the town mains and into a 90,000-gallon elevated steel tank, which maintains an operating pressure of 50–70 psi in the distribution system. The small-capacity well, which has a reported depth of 900 feet, produces only a few gallons per minute of soft water that is piped to a few homes.

The valley-fill deposits yield 45–1,840 gpm to the large-capacity wells (yields measured by U.S. Geol. Survey); the average yield is about 750 gpm. Drawdowns range from 3 to 37 feet and specific capacities from 10 to 300. Generally the coefficients of permeability and transmissibility are high. The yields of wells in places on the

flood plain or on the Kersey and Kuner terraces where the saturated thickness is greatest generally are greater than yields from wells near the margins of the valley.

It is estimated that about 30,000 acre-ft. of ground water is pumped from the large-capacity wells in the district during a year of normal precipitation and pumping. The estimated quantity of recoverable ground water in storage in November 1957 was 250,000 acre-ft. The hydrographs of long-term observation wells in the district (fig. 10) indicate that the average rates of ground-water discharge and recharge almost balance and that the ground-water reservoir apparently is not being depleted by pumping.

In the southern part of this district the ground water ranges in specific conductance from 1,410 to 1,800 micromhos per cm and is of the calcium sulfate type, whereas in the northern part it ranges in specific conductance from 1,000 to 1,400 micromhos per cm and is of the calcium bicarbonate type. Most of the water used for irrigation in the southern part of the district is diverted from the river near Denver, and most of the water used in the northern part is diverted near Fort Lupton. The farther the water travels by canal through irrigated areas, the more mineralized the underlying ground water becomes. The water of highest mineralization in the district is that in the valleys of Big and Little Dry Creeks and is of the sodium sulfate type.

NORTHERN BOUNDARY OF T. 3 N. TO KUNER

In this district the South Platte River valley is much broader than it is in the district to the south. The valley trends northeastward to Greeley, where it is joined by the Cache la Poudre River valley, and then it swings southeastward to Kuner. The South Platte River follows a course along the northwest and north sides of the valley. The valleys of several major tributaries—St. Vrain Creek and the Big Thompson and Cache la Poudre Rivers—enter the main valley from the west; Beebe Draw and the Box Elder Creek valley enter from the south; and the valleys of Sand, Lone Tree, and Crow Creeks, which are relatively small, enter from the north. Rolling uplands and gentle slopes border the South Platte River valley on the south side and on the north side downstream from Greeley. A rather steep escarpment borders the northwest side of the valley in Tps. 3 and 4 N. The uplands that border the valley are drained by numerous intermittent and ephemeral streams.

The Fox Hills sandstone and the Laramie formation underlie the district; these consolidated rocks form the uplands and crop out in the escarpment along the northwest side of the South Platte River valley. Along the valley the valley-fill deposits range in thickness from 85 to 125 feet. Channels eroded into the bedrock by ancestral

streams and then buried beneath unconsolidated deposits are shown on plate 4. The average width of the valley is about 5 miles between the southern boundary of the district and Greeley. The valley widens abruptly at Greeley, where the valleys of the South Platte and the Cache la Poudre Rivers merge, and then narrows gradually to a width of about 3 miles at Kuner. A striking feature of the floor of the valley is the broad, flat Kersey terrace, which extends along the southeast side of the valley (fig. 3).

The slope of the water table and the direction of movement of the ground water are diagonally downstream toward the South Platte and Cache la Poudre Rivers, which are gaining water from the ground-water reservoir. Beneath the flood plain and the Kersey and Kuner terraces the gradient of the water table is about 6 ft. per mile, but in the slope-wash deposits that fringe the valley fill the gradient steepens considerably. Probably the steepening is caused by the relatively low permeability of the slope-wash deposits and by the slope of the bedrock surface. The mound on the water table downgradient from Lower Latham Reservoir shows that water is seeping from the surface reservoir into the ground-water reservoir. The small irregularities in the shape and slope of the water table beneath the Kersey terrace probably are caused by differences in the permeability of the sediments.

The depth to water is less than 10 feet beneath the flood plain and the surface of the slope wash, but it ranges from 10 to 40 feet beneath the terraces. The maximum annual fluctuation of the water table in the district during the period 1956–57 was about 10 feet. Records of the U.S. Geological Survey's observation wells (figs. 12 and 13) show a normal seasonal rise and decline of the water table, with minor monthly fluctuations due to discharge by pumping and recharge from irrigation. The hydrographs of the water level in long-term observation wells B4–66–15ccc and –31dcc (fig. 10), however, show a marked net decline in the water table over a period of years. The most significant drop was during the middle 1950's, a period of low precipitation and heavy pumping. The hydrograph of well B5–65–26bcc does not show a pronounced long-term downward trend, probably because the ground-water reservoir in that area was being recharged by seepage from Lower Latham Reservoir.

Almost all the water withdrawn from the valley-fill deposits in the district is used for irrigation. Water is pumped from wells to supplement the irrigation water diverted from the South Platte River and its major tributaries. Because priorities on surface water are low, the amount of pumping in a particular year depends largely on the amount of available water in the river, which generally is not adequate for irrigation needs. A well-location map prepared by Code (1943) shows 290 irrigation wells in 1940; 550 were inven-

toried by the end of 1957. The number of irrigation wells ranges from 0 in some sections to 18 in sec. 16, T. 4 N., R. 66 W.; the average concentration of irrigation wells is 5 per section. Nearly all the wells reach bedrock; most are drilled but some are dug. Only a very few are lined with concrete casing, metal casing generally being used. Most of the wells are equipped with electrically driven turbine pumps, although a few centrifugal pumps and a few internal-combustion engines are used.

Greeley (population 25,000) is supplied primarily with surface water, ground water being pumped from small-capacity wells for garden and lawn irrigation only. The municipal water supply for Kersey (population 330) is obtained from two wells that tap the valley-fill deposits and together yield about 150,000 gpd, or about 170 acre-ft per year. Electrically driven turbine pumps on the wells force the water into a 56,000-gallon elevated steel tank, which maintains pressures ranging from 46 to 72 psi in the distribution system. LaSalle (population 1,200) is supplied by two large-capacity drilled metal-cased wells that obtain water from the valley-fill deposits. Electrically driven turbine pumps force the water into a 50,000-gallon elevated steel tank which maintains an average operating pressure of 50 psi in the distribution system. The average rate of pumping is about 175,000 gpd, or about 200 acre-ft per yr.

Yields of the large-capacity wells that tap the valley-fill deposits in this district range from 60 to 2,040 gpm; the average yield is 850 gpm. Drawdowns ranged from 1 to 48 feet. Some of the wells had a specific capacity greater than 200. As shown in figure 16, the coefficients of permeability and transmissibility determined from all but one of the aquifer tests in this district were high; low coefficients of permeability and transmissibility were determined from the test at well B4–65–19abd, which is near the margin of the valley. The greatest yields are obtained from the deposits that underlie the flood plains of the rivers and the Kersey and Kuner terraces, although locally poor well construction and zones of low permeability reduce yields and increase drawdowns.

It is estimated that about 70,000 acre-ft of water is pumped from the large-capacity wells during a year of normal precipitation and pumping. According to the map showing saturated thickness (pl. 8), about 760,000 acre-ft of recoverable ground water was in storage in November 1957. The steady downward trend of water levels in long-term observation wells B4–66–15ccc and B4–66–31dcc, however, strongly suggests that the ground water in storage, at least in the southern part of the district, is being slowly depleted by pumping. These hydrographs indicate that the water levels had not recovered by the end of 1957.

Most of the ground water in the southwestern part of this district has a specific conductance of less than 1,400 micromhos per cm and is of the calcium bicarbonate type. Most of the water in the northern part of the district, however, has a specific conductance of more than 1,800 micromhos per cm and is of either the calcium sulfate or the sodium sulfate type. The degree of mineralization and the chemical type of water in the northern part are greatly influenced by the water from the valleys of the Cache la Poudre River, Box Elder Creek, Crow Creek, and Beebe Seep (table 3).

Most of the water in the Cache la Poudre River valley is very hard, but water produced by some domestic wells in the vicinity of Greeley is relatively soft. The hardness of the water from well B6–65–31cdb1, 14 feet deep, was 720 ppm, although the hardness of the water from well B6–65–31cdb2, 90 feet deep, was only 88 ppm. Also, according to local residents, other wells produce relatively soft water; these wells reportedly have low yields, but the yields are sufficient to supply domestic users.

The highest specific conductance in this district was that of water from well B6–64–35baa in the Crow Creek valley. The salinity hazard of much of the water in this district is high or very high. The apparently successful use of the water for irrigation may be attributed to good soil permeability and adequate natural drainage and to the medium or high salt tolerance of the principal irrigated crops—sugar beets, corn, alfalfa, potatoes, and beans.

BEEBE DRAW

Beebe Draw, an elongate valley bordered on both sides by rolling uplands, is drained by Beebe Seep. In most of its reaches the channel of the seep has been deepened, straightened, and repositioned by dredging. The flow of the stream is sustained by irrigation water from Barr Lake and from wells, by ground-water inflow, and by precipitation. Ephemeral streams drain the uplands that border the draw. The floor of the valley is an uneven surface that slopes gently upward to the valley sides. Low mounds dot the surface of the valley floor, and sand dunes form a distinctive topography north of both Milton Reservoir and the town of Hudson. Beebe Draw extends northeastward from Barr Lake, merges with the Box Elder Creek valley immediately north of Hudson and then diverges from the Box Elder Creek valley and extends northward, opening into the South Platte River valley immediately north of Lower Latham Reservoir. The bedrock, into which a single ancestral channel was eroded (pl. 4) is the Arapahoe formation in the southern part of the district and the Laramie formation in the northern part (pl. 1). Almost everywhere the bedrock is mantled by unconsolidated deposits; those underlying the floor of the

valley are 70–100 feet thick in the deepest part of the ancestral valley. Logs of wells and test holes show that the valley-fill deposits grade from cobbles and boulders in the lower part to increasingly finer gravel, sand, and clay in the upper part. The fill is fringed by slopewash deposits, and its width averages about 2 miles.

The contours on the water table (pl. 5) show a uniform downvalley gradient of about 14 feet per mile, except immediately downgradient from the three reservoirs where the gradient steepens abruptly. This abrupt steepening indicates that the ground-water reservoir is recharged appreciably by seepage from the surface reservoirs. Surface water spread for irrigation also contributes substantially to recharge. The contours show that some ground water may be moving into Beebe Draw from the Box Elder Creek valley. The depth to water ranges from 0 to 60 feet. The depth to water and the shape of the water table indicate that in some reaches the ground water is discharging into Beebe Seep and other drains, but that in some places the water table is considerably below the surface streams and the ground-water reservoir is being recharged by seepage from the streams and canals. In the reach through Tps. 1 and 2 N. the depth to water reaches about 60 feet, but in the immediate vicinity of the three reservoirs and in some places between Milton and Lower Latham Reservoirs the depth to water is less than 5 feet. The movement of ground water inward from the sides of the valley probably is caused by the slope of the bedrock surface (pl. 4). Hydrographs of the U.S. Geological Survey's observation wells show only a seasonal rise and decline (figs. 12 and 13). The record for well B4–65–15acb shows a rise in the water table from 1956 to 1958; the water level in well B1–65–4cbb had an overall decline from 1955 to 1958 and during 1957 it showed the effects of pumping nearby wells. The maximum yearly fluctuation of the water table in well B1–65–4ccb during the short period of record was about 7 feet. Although the long-term records of the fluctuations of the water table in Beebe Draw are incomplete, they show a net lowering of the water levels in wells in the central part of the district. The decline is most marked for the period 1953 to 1958 (Code, 1958).

All the large withdrawals of ground water from the valley-fill deposits in this district, except those from well C1–66–12cbb which is pumped for irrigation and to fill ponds for the use of wildfowl, are used for irrigation. The ground water is used to supplement surface irrigation water released from the reservoirs and diverted from the South Platte River. Code's map (1943) shows 25 irrigation wells in Beebe Draw in 1940, whereas at the end of 1957 there were about 130. The irrigation wells tapping the valley fill, however, are not as concentrated locally as in other parts of the report area. Several

sections contain no wells and the greatest concentration per section is only nine in sec. 30, T. 1 N., R. 65 W. The average is about two wells per section.

Most of the irrigation wells are drilled to bedrock, lined with metal casing, and equipped with electrically driven turbine pumps. A few wells are dug and lined with concrete casing. Very few internal-combustion engines are in use, and only one well is equipped with a centrifugal pump.

The valley-fill deposits, especially the beds of cobbles and boulders, contain large quantities of unconfined ground water. Yields from irrigation wells that were measured by the U.S. Geological Survey ranged from 475 to 1,840 gpm, and the average yield of 900 gpm is the highest in the report area. The water-level drawdown in many of the wells yielding more than 1,000 gpm was less than 15 feet. Specific capacities ranged from 30 to 235. Data from all the aquifer tests except one (table 5) show that the average coefficients of permeability and transmissibility are the highest in the report area. An aquifer test at well B2–65–16bcc indicated only a moderate coefficient of permeability and transmissibility, apparently because the water-bearing material tapped by the well consists, according to the driller's log, of sand and silt containing no gravel or cobbles.

Although most of the wells yield water copiously, yields are only moderate if wells are poorly constructed of if they produce from the slope-wash deposits. The yields of wells generally are greater near the center of the ancestral valley, where the saturated thickness is greatest and where the lower part of the valley-fill deposits consist of gravel, cobbles, and boulders, than near the edges of the channel.

Withdrawal of ground water for irrigation during a year of normal precipitation and pumping is estimated to be about 15,000 acre-ft. It is estimated further that about 320,000 acre-ft of recoverable ground water was in storage in November 1957.

Little is known of the effects of large-scale pumping on the ground-water regimen in Beebe Draw because of large gaps in the long-term records of water-table fluctuations. Incomplete hydrographs of wells B1–65–4bb1 and B2–65–16bc, prepared by Code (1958), show a net lowering of water levels, at least locally, since 1953. However, no serious net declines of the water table or of interference between wells had been reported by the time the fieldwork for this project was completed (end of 1957).

The quality of the ground water in Beebe Draw, as in the South Platte River valley, is closely associated with the quality of the surface water. Recharge from Barr Lake and the six large canals that flow through or along the edge of Beebe Draw dilutes the ground water. The specific conductance of water from well C1–66–32aad, near the

inflow end of Barr Lake, was 1,340 micromhos per cm, and the specific conductance of water from wells C1–66–1baa and B1–65–30dcb, downgradient from Barr Lake, was 1,100 and 1,240 micromhos per cm, respectively. Although the average specific conductance of water in Barr Lake is not known, the specific conductance of an outflow sample on September 10, 1957, was only 411 micromhos per cm (analysis not given in this report). The specific conductance of the ground water tends to increase downvalley. Recharge from Milton Reservoir probably dilutes the ground water somewhat in the northern part of the draw.

In the southern part of Beebe Draw, near Barr Lake, the ground water is of the calcium bicarbonate type; in the central part it is of the calcium sulfate type; and in the northern part it is of the sodium sulfate type.

BOX ELDER CREEK VALLEY

The narrow valley of Box Elder Creek extends almost the full length of the report area, a distance of about 40 miles. Box Elder Creek follows a course along the east side of its valley through most of its course in the report area; in the lower reaches of the valley the channel of the creek has been repositioned by dredging. Rolling uplands border the valley and, in some places where the creek has cut laterally into the bedrock, the valley wall is a rather steep bluff. From the southern boundary of the report area the valley trends northward to its junction with Beebe Draw, where it turns northeastward away from Beebe Draw and leaves the area near Kuner. The floor of the valley is an uneven surface of low mounds and shallow depressions, and north of Hudson it is formed by sand dunes. Sand dunes also lap onto the east side of the valley floor in the northern reach.

The ancestral valley was eroded into the Dawson arkose in the extreme southern part of the area, into undifferentiated Cretaceous and Tertiary deposits in the southern and central parts, and into the Laramie formation in the northern part (pls. 1 and 4). The bedrock formations are mantled by unconsolidated deposits except for a few outcrops along the stream valley. The valley-fill deposits range in thickness from about 85 feet in the deepest part to 0 along the sides. Slope wash fringes the valley fill in most places. The width of the fill ranges from 1 to 2½ miles, except in T. 4 N., R. 64 W., where the width increases to about 3½ miles. Logs of wells and test holes show that the valley-fill deposits consist of sand, gravel, and clay, and that they do not contain abundant cobbles and boulders as do the valley-fill deposits in Beebe Draw and in the South Platte River valley.

The water table in the Box Elder Creek valley slopes in a general downvalley direction. The gradient of the water table averages

about 23 feet per mile south of Hudson, but it decreases to about 18 feet per mile and is nearly uniform northward from Hudson. In the vicinity of sec. 11, T. 4 N., R. 64 W., however, there is a flattening of the slope, probably due to an increase in the permeability of the sedimentary rock. Depths to water and the shape of the water table show that Box Elder Creek was not gaining water from the ground-water reservoir in November 1957. The creek is dry during much of the year but is a source of recharge to the ground-water reservoir when it flows and especially so when it is at flood stage. Other sources of recharge are surface water that is spread for irrigation and precipitation that falls within the basin. Immediately after a flood, when water from Box Elder Creek is recharging the ground-water reservoir, a ridge probably is formed on the water table beneath the bed of the creek. The contours around Horse Creek, however, indicate that the creek is gaining ground water, probably by seepage from Horse Creek Reservoir. Recharge from the Ireland Reservoir No. 5 apparently is causing the mound in the water table downstream from the reservoir. The contours in the area where the valleys of the Beebe Draw and Box Elder Creek valley merge show that some of the ground water in Box Elder Creek valley is moving into the valley-fill deposits in Beebe Draw. The slight inward movement of ground water along the edges of the valley probably is caused by the slope of the bedrock surface.

Depths to water in the valley range from less than 5 feet to about 40 feet and average 22 feet. Hydrographs of the U.S. Geological Survey's observation wells (figs. 11, 12, and 13) show that the maximum annual fluctuation in well B1-65-12ccd2 was about 13 feet, part of which was due to the pumping of a nearby irrigation well. The records of the long-term observation wells, except well B2-64-30cbc, show a pronounced downward trend in the water levels since 1950 (fig. 10). In the vicinity of this well, ground-water underflow from Ireland Reservoir No. 5 probably recharges the ground-water reservoir. Although the water levels had risen by the spring of 1958, they still were far below the average of record in most of the wells. The only surface water available for irrigation in the district is that diverted from the few reservoirs and from Box Elder Creek when it is at flood stage. Therefore, irrigation is largely dependent on water pumped from wells. All the large withdrawals of ground water from the valley-fill deposits, except from the Hudson municipal wells, are used for irrigation. Code's well-location map (1943) shows only 70 irrigation wells in 1940; by the end of 1957 there were 210. The number of wells per section ranges from 0 in several to 12 in secs. 12 and 13, T. 1 N., R. 65 W., and the average is three. Locally, however, the irrigation wells are too closely spaced, and as a result mutual interference

decreases yields and increases drawdowns. Most of the wells are drilled to bedrock, are lined with metal casing, and are equipped with electrically driven turbine pumps. A few of the wells are dug and lined with concrete casing. Only two wells are equipped with centrifugal pumps and only one pump is driven by an internal-combustion engine.

Hudson (population 430) is supplied with water from two drilled metal-cased wells that obtain water from the valley-fill deposits. The wells, which are outside the city limits, are equipped with electrically driven turbine pumps that force water into a 44,000-gallon elevated steel tank. An average operating pressure of about 35 psi is maintained in the city distribution system. About 125,000 gpd, or about 140 acre-ft per year, is pumped from the wells for municipal use.

Pumping from the irrigation wells in this district has been very heavy during recent years. Yields from the wells that were measured by the U.S. Geological Survey ranged from 85 to 1,090 gpm and averaged 550 gpm. Drawdowns ranged from 7 to 32 feet and specific capacities ranged from 5 to 135. The coefficients of permeability and transmissibility are relatively low (table 5) compared to those in the rest of the report area. The water levels in many of the wells south of Hudson declined to the pump intakes during the 1957 pumping season, and some wells were not used. The largest yields generally are obtained from wells near the axial part of the valley; the slope-wash deposits along the edges of the valley fill are poor producers. The comparatively small average yields of wells in the district probably are due to the declining water table and to the lower permeability of the valley-fill deposits, which contain a large percentage of clay and silt. Heavy pumping eventually could lower the regional water table below the intakes of some pumps.

It is estimated that about 20,000 acre-feet of ground water is pumped from the valley-fill deposits during a normal year. The estimated quantity of recoverable ground water in storage in November 1957 was about 320,000 acre-ft. Declining water levels indicate that ground water is being taken from storage; that is, recharge is not balancing discharge. The decline of the water table in this district is the most marked in the report area.

In the southern part of this district, the water generally has a specific conductance of less than 1,400 micromhos per cm and is of the calcium bicarbonate type. In the northern part, the water generally has a specific conductance of more than 1,800 micromhos per cm and is of the calcium sulfate type.

CONCLUSIONS

Unconsolidated valley-fill deposits of sand, gravel, cobbles, and boulders of Quaternary age are the important water-bearing forma-

tions in the report area. These deposits are the principal source of ground water in the stream valleys and, locally, they yield as much as 2,000 gpm to wells, although the average yield is about 700 gpm. The low to moderate yield of some wells probably is due to poor construction of the wells, and that of others to low transmissibility of the aquifer. The ground water in the valley-fill deposits is unconfined, except locally, and the depth to water ranges from 0 to about 80 feet. Ground water enters the area by underflow. The ground-water reservoir in the area is recharged also by precipitation and by seepage from irrigated tracts, reservoirs, canals, and streams. Ground water is discharged within the area by evapotranspiration, seepage into streams, springs and seeps, and pumping from wells. The remainder of the ground water leaves the area by underflow through the valley-fill deposits.

The South Platte River gains water from the ground-water reservoir throughout its course in the area. Beebe Seep at some times and places is a gaining stream and at others a losing stream. Water from Box Elder Creek infiltrates into the underlying unconsolidated deposits, especially during flood stage.

Development of ground-water supplies from the valley-fill deposits has been rapid since 1940; the number of large-capacity wells increased from about 700 in 1940 to about 1,700 at the end of 1957. Ground water is used principally for irrigation, but large amounts are used also for municipal and industrial supplies, and most of the water for domestic and stock use is obtained from wells. It is estimated that about 250,000 acre-ft of water in 1956 and about 100,000 acre-ft in 1957 was pumped from the large-capacity wells, and that about 500 acre-ft is pumped from domestic and stock wells annually. It is estimated that about 2 million acre-ft of recoverable ground water is stored in the valley-fill deposits in the report area.

Further ground-water development may be feasible in some parts of the area but not in others. The insignificant net change in ground-water levels between 1929 and 1958 in the South Platte River valley between Denver and the northern boundary of T. 3 N. indicates that ground-water withdrawals during that period did not deplete the supply in storage. Even during the period 1954–57, when precipitation was subnormal and pumpage was correspondingly greater, the net change in water levels was very slight. Apparently, ground-water withdrawals through 1957 in this part of the area have resulted in the salvage of water that otherwise would have been discharged by natural processes. In places where the water table is shallow, water now lost through evapotranspiration could be salvaged through an increase in pumping. Heavy pumping near the river, however, might induce recharge from the river and compete with surface-water use. In parts

of the district between Denver and the base line, wells are so closely spaced that when pumped for long periods the water level declines to the pump intake; additional large-capacity wells in other parts of the district should be spaced farther apart so as to avoid mutual interference and a subsequent local lowering of the water table.

There appears to be a danger of overdevelopment of the ground-water supply in the South Platte River valley in T. 4 N., R. 66 W. Although the net change in water levels during the period 1929–50 was relatively small, a pronounced steady decline, due partly to increased pumping and partly to subnormal precipitation, has occurred since 1950. Water levels in the area immediately north of Lower Latham Reservoir do not show a marked long-term decline, probably because seepage from the reservoir is recharging the ground-water reservoir. Little is known about the net change in water levels in the rest of the district between the northern boundary of T. 3 N. and Kuner because long-term records of water-level fluctuations are not available.

Although long-term records of water-level fluctuations in Beebe Draw are incomplete, they indicate a net decline of ground-water levels, at least locally. High coefficients of permeability and transmissibility of the valley-fill deposits, however, indicate that the district may be able to support additional well-planned ground-water development. An estimated 20,000 acre-ft of ground water was pumped in 1956, apparently without material interference among wells or noticeable depletion of ground water in storage. If properly spaced, additional wells of large capacity should not seriously deplete the ground-water reservoir.

The maximum development of ground water probably has been reached or exceeded in the Box Elder Creek valley, especially in the stretch between Hudson and the southern boundary of the report area where water in the irrigation wells commonly decline to the pump intake when the wells are pumped during extended droughts, and where the coefficients of permeability and transmissibility of the valley-fill deposits generally are comparatively low. Several instances have been reported of interference among wells. Long-term records show that ground-water levels throughout the valley have declined sharply since 1950, indicating rather rapid depletion of the ground water in storage.

The extent to which development of ground water in the districts can be safely increased and sustained depends on (1) the amount of ground water available, (2) the rate at which it is withdrawn, and (3) the rate at which it is replenished. An indication of the amount of ground water available is the average annual amount of natural discharge from a district; the amount available determines the upper limit for development. In practice, however, feasible development

must be less than ground-water discharge because not all the natural discharge can be intercepted, and because of limiting hydrologic and legal factors.

The average amount of water than can be pumped from the valley-fill deposits over a long period without exceeding the rate of recharge and permanently depleting the supply in storage and thus progressively lowering the water table should be determined separately for each district. This amount is the safe perennial yield. Its determination requires records for several years of pumpage, water-level changes, precipitation, runoff, and an analytical appraisal of these data. The hydrologic features of the report area are complex, and the safe yield can be determined only by further study and systematic observations while additional development proceeds.

As new wells are brought into production, water levels will decline, but such a decline alone is not necessarily proof of overdevelopment. Some water-level decline is inevitable if a large amount of water is taken from the ground-water reservoir. The critical point, however, is whether or not the water levels recover after the pumping season, or after several pumping seasons during a series of dry years. In a natural ground-water regimen, discharge is mainly equal to recharge; that is, the system is in dynamic equilibrium. In an artificially altered regimen, such as the report area, discharge will continue to equal recharge only so long as the safe perennial yield is not exceeded.

Much of the ground water discharged from wells in areas where the water table is at or near the land surface is salvaged water, because lowering the water table reduces natural discharge by evapotranspiration. Also, artificial lowering of the water table creates space for storage of additional recharge. The safe perennial yield is not being exceeded in such areas. In other areas, however, large-scale pumping may deplete ground water in storage and reduce the natural discharge into streams to such an extent that surface-water rights are infringed upon and water levels in wells drop below the intake of pumps. Most of the large-capacity wells in the project area reach, or nearly reach bedrock; therefore, the total depth of the well is the maximum depth to which the water table and the intake pipe can be lowered.

Two important factors are involved in the concept of safe perennial yield, one being the hydrologic factors just discussed and the other being the legal factor. Although, strictly speaking, the maximum possible withdrawal of ground water from a district is limited by hydrologic factors alone, the maximum actual withdrawal may be limited by legal factors. It may be decided by competent legal authority to restrict ground-water development to a yearly withdrawal rate that

will provide the greatest long-term benefits for all water users and prevent future controversies. Therefore, it should not be inferred from this report that the report area can safely, economically, and legally support a large additional number of large-capacity wells.

Continued collection and study of data is needed to determine the safe perennial yield of the aquifers in the report area, and to assist orderly and efficient development of the ground water of the valley-fill deposits. Such an investigation should include (1) maintenance of complete and accurate records on additional large-capacity wells that are installed in the area; (2) continued measurement of water levels in a network of observation wells; (3) systematic collection of discharge and power-consumption records for large-capacity wells and from those records, computation of the total yearly volume of withdrawals; (4) evaluation of all sources of recharge to and discharge from the ground-water reservoir; (5) quantitative studies of the relation of streamflow to ground water; (6) collection and evaluation of additional data on the chemical quality of the water.

The collected data should be evaluated periodically in order to detect current or impending overdevelopment of the ground-water resources. Such data and periodic review will make water problems easier to solve, and they may indeed provide the basis for development of an integrated surface- and ground-water irrigation system involving the utilization of artificial recharge and discharge as a means of balancing the effects of wet and dry years.

Water from the valley-fill deposits in most of the report area has a specific conductance of 1,000–1,800 micromhos per cm and is of either the calcium bicarbonate or the calcium sulfate type. The water is suitable for irrigation in most places but has a high or very high salinity hazard and in some places has a high leaching requirement. It is of poor quality for public-supply and domestic use because it is very hard. In a few sections in T. 2 S., R. 67 W., near Derby, the water has a specific conductance of more than 4,000 micromhos per cm and is of the calcium chloride type, a type found nowhere else in the report area. The high specific conductance and the water type indicate contamination of the ground water by waste from the arsenal. In the downvalley parts of the South Platte River valley and of most of the tributary valleys, the water has a specific conductance of about 2,250 micromhos per cm and is of the calcium sulfate or sodium sulfate type. Near Denver ground water in the Sand Creek and South Platte River valleys is contaminated by petroleum wastes, but the severity and areal extent of the contamination were not determined.

The quality of the water in the valley-fill deposits in the report area is similar to the quality of the water in the surface streams and is affected by irrigation practices. Use of the water for irrigation tends

to increase the mineralization and to change the type of the water from calcium carbonate to calcium sulfate or sodium sulfate.

Water from the bedrock differs widely in mineralization from one stratigraphic unit to another, as well as within units; the specific conductance of ground water that was sampled ranged from 336 to 5,040 micromhos per cm. In most of the units the water is of the sodium bicarbonate type, is soft, and has a relatively high concentration of fluoride. Water from the Dawson arkose was the least mineralized of the water sampled, and water from some strata in the Laramie formation was the most mineralized. Water from the bedrock probably is poor for irrigation and ranges from poor to good for public supply and domestic use.

It would be advisable to study long-term changes in quality of water from key wells, to determine the source and extent of the contamination by petroleum waste in the valleys of Sand Creek and the South Platte River and to determine the extent of and potential for development of the aquifer that produces relatively soft water in the vicinity of Greeley.

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INDEX

[Where several page numbers appear, major references are in italic]

O

The U.S. Geological Survey Library has cataloged this publication as follows:

Smith, Rex Onis, 1924–
Ground-water resources of the South Platte River basin in western Adams and southwestern Weld Counties, Colorado, by Rex O. Smith, Paul A. Schneider, Jr., and Lester R. Petri. Washington, U.S. Govt. Print. Off., 1963.

vi, 132 p. illus., maps, diagrs., profile, tables. and portfolio (fold. maps (part col.) diagrs.) 24 cm. (U.S. Geological Survey. Water-supply paper, 1658)
Bibliography: p. 128–130.
(Continued on next card)
Smith, Rex Onis, 1924– Ground-water resources of the South Platte River basin in western Adams and southwestern Weld Counties, Colorado. 1963. (Card 2)

1. Water, Underground—Colorado—South Platte River basin. 2. Water-supply—Colorado—South Platte River basin. 3. Water—Analysis. I. Schneider, Paul A 1931– joint author. II. Petri, Lester R 1924– joint author. III. Title: South Platte River basin, Colorado. (Series)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EXPLANATION

Specific conductance in micromhos per centimeter at 25° C

⊕ Less than 1000

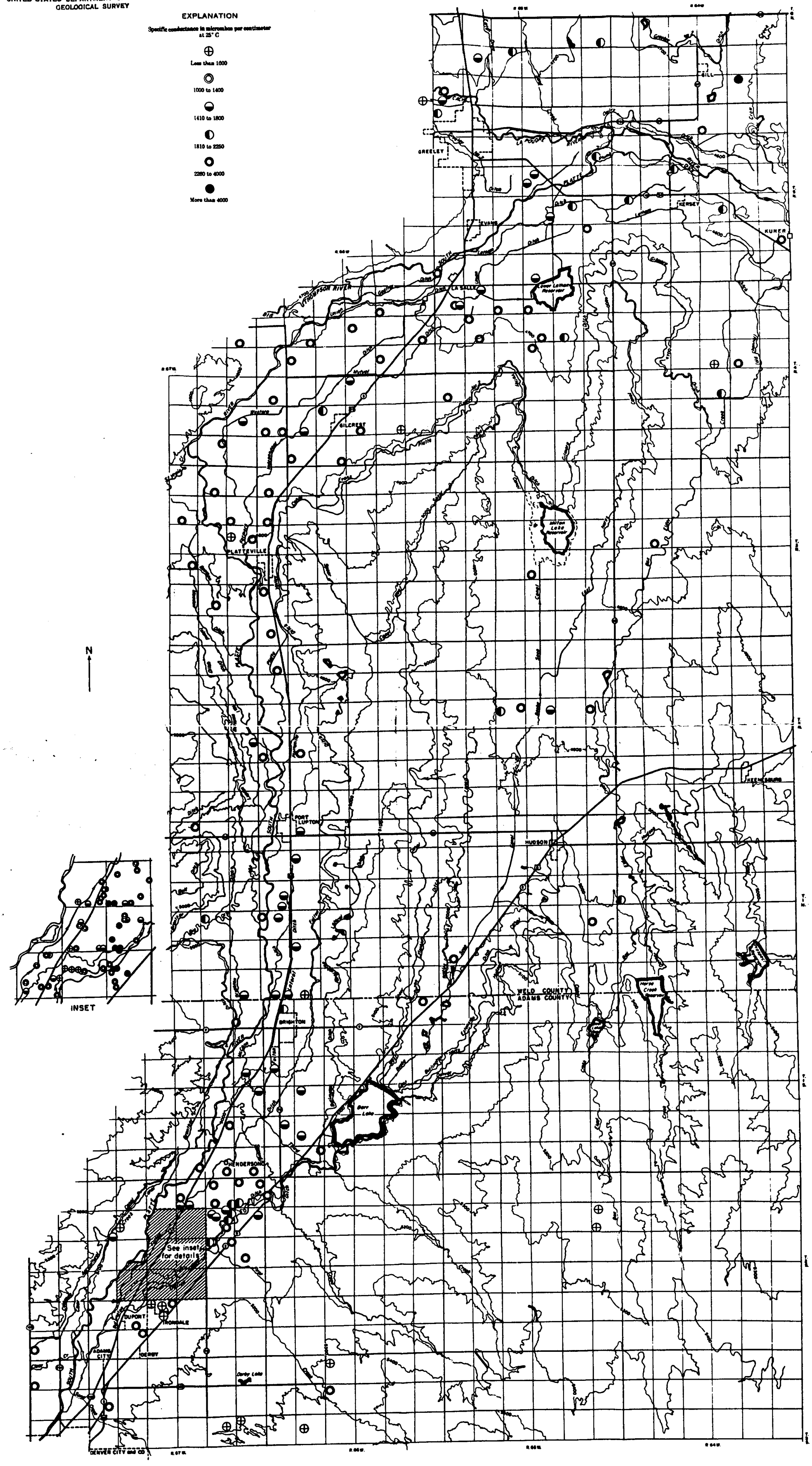
◎ 1000 to 1400

◒ 1410 to 1800

◐ 1810 to 2250

○ 2260 to 4000

● More than 4000



MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO, SHOWING RANGES IN SPECIFIC CONDUCTANCE OF WATER FROM THE VALLEY-FILL DEPOSITS

1 0 1 2 3 4 5 MILES

CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

84324R02

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EXPLANATION

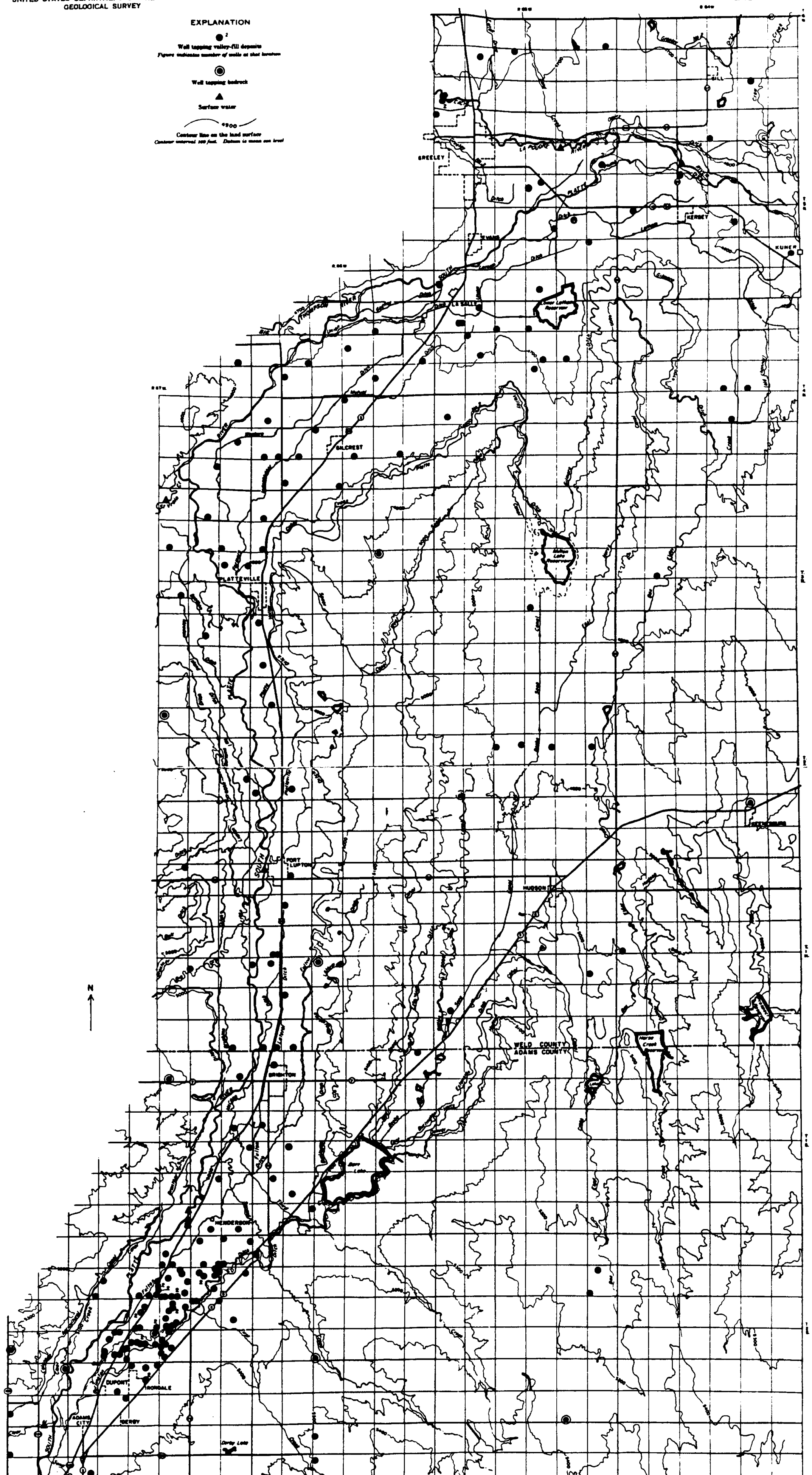
Well tapping valley-fill deposits
Figure indicates number of wells at that location

Well tapping bedrock

Surface water

4900

Contour line on the land surface
Contour interval 100 feet. Datum is mean sea level



MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO, SHOWING CHEMICAL-QUALITY SAMPLING SITES, NETWORK OF IRRIGATION CANALS, AND CONTOURS ON THE LAND SURFACE

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EXPLANATION

Pleistocene and Recent — QUATERNARY

Qds

Dune-sand deposits

Fine to medium sand and minor amounts of clay and silt. Serve mainly as medium for recharge from precipitation. Mapped only where of distinctive topographic form. Yield small quantities of water locally to domestic and stock wells

Qsw

Slope-wash deposits

Poorly sorted clay, silt, sand, and gravel. Yield small to moderate quantities of water to domestic and stock wells and to a few irrigation wells

Valley-fill deposits:

Qal

Alluvium

Interbedded clay, silt, sand, and gravel. Contains some cobbles and boulders. Includes some slope wash along edges of Beebe Draw and Box Elder Creek valley. In area east of Derby includes deposits above and older than those of Kersey terrace. In Beebe Draw the lower part consists of cobbles and boulders and some interbedded, altered volcanic ash. Yields moderate to large quantities of water to irrigation, municipal, industrial, domestic, and stock wells

Qt_1

Deposits of the Kuner terrace

Interbedded clay, silt, sand, and gravel. Contains some coarse gravel. Yield large quantities of water to irrigation, municipal, industrial, domestic, and stock wells

Qt_2

Deposits of the Kersey terrace

Interbedded clay, silt, sand, and gravel. The lower part consists of cobbles and boulders. Yields large quantities of water to irrigation, municipal, industrial, domestic, and stock wells

CRETACEOUS AND TERTIARY

Upper Cretaceous and Paleocene

TKd

Denver formation

Light-gray, bluish-gray, and brown clay, soft shale, and siltstone containing much carbonaceous material, interbedded with lenticular poorly sorted generally moderately indurated yellowish-brown sandstone and conglomerate. Lower sandstones and conglomerates especially contain much andesitic material. Yields small quantities of water to domestic and stock wells

Upper Cretaceous

Ka

Arapahoe formation

Upper 400 feet consists of soft predominantly blue or gray sandy shale and clay and a few lenticular sandstones which supply small yields to domestic and stock wells.

Lower 200 feet consists of white to yellow arkosic sand, gravel, and conglomerate, variously indurated, and minor amounts of shale and clay. Yields moderate quantities of water to public-supply, industrial, domestic, and stock wells

Kl

Laramie formation

Upper 400 feet consists of olive-gray silty shale; contains lenticular beds of sandstone and numerous carbonaceous beds of clay and seams of lignite. Lower 200 feet consists of blue-gray silty shale, several relatively thin beds of sandstone, and fairly thick beds of subbituminous coal. At the base is a thick persistent sandstone; immediately above are two thinner sandstone beds that locally coalesce with the thick sandstone. Some of the upper beds of sandstone and the basal beds of sandstone yield small to moderate supplies of water to industrial, public-supply, domestic, and stock wells

TKu

Denver, Dawson, Arapahoe and Laramie formations undifferentiated (see text)

Kfh

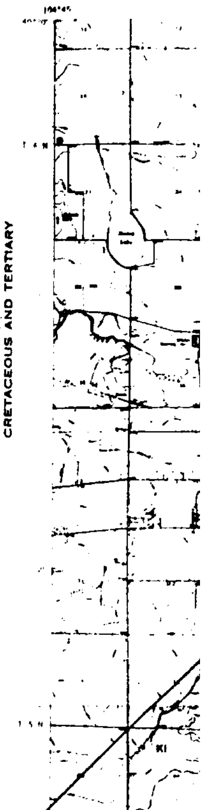
Fox Hills sandstone

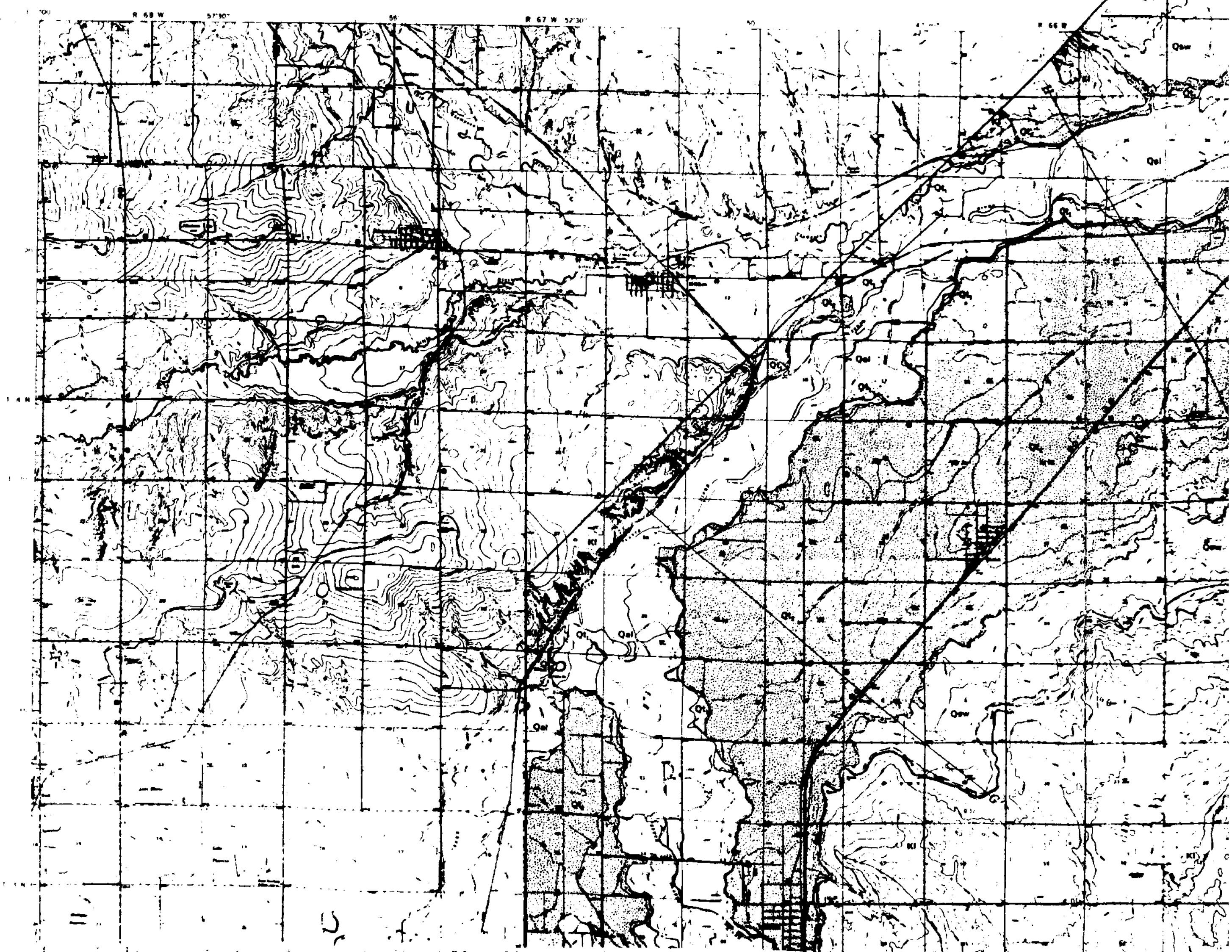
Uniformly bedded buff to pale-yellow friable medium-grained sandstone and interbedded gray to black silty shale and silty sandstone. About 50 to 60 feet of massive sandstone at top. Yields small to moderate quantities of water to public-supply, industrial, domestic, and stock wells

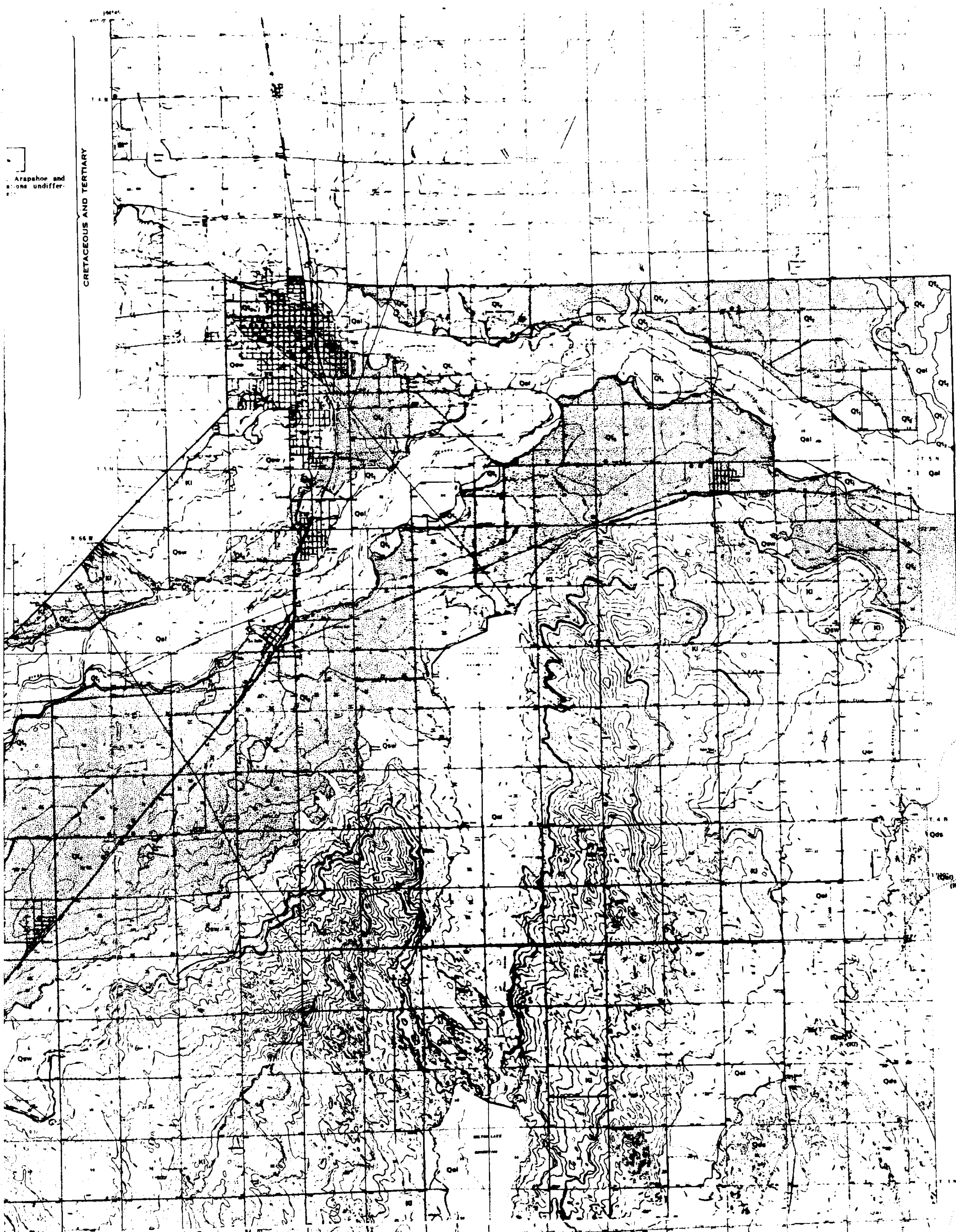
Contact

Dashed where approximately located; dotted where inferred or covered by surficial material; queried where doubtful

Geologic sections found on plates 2 and 3






CRETACEOUS AND TERTIARY
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T 4 N
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Qsw
Kl
Qds

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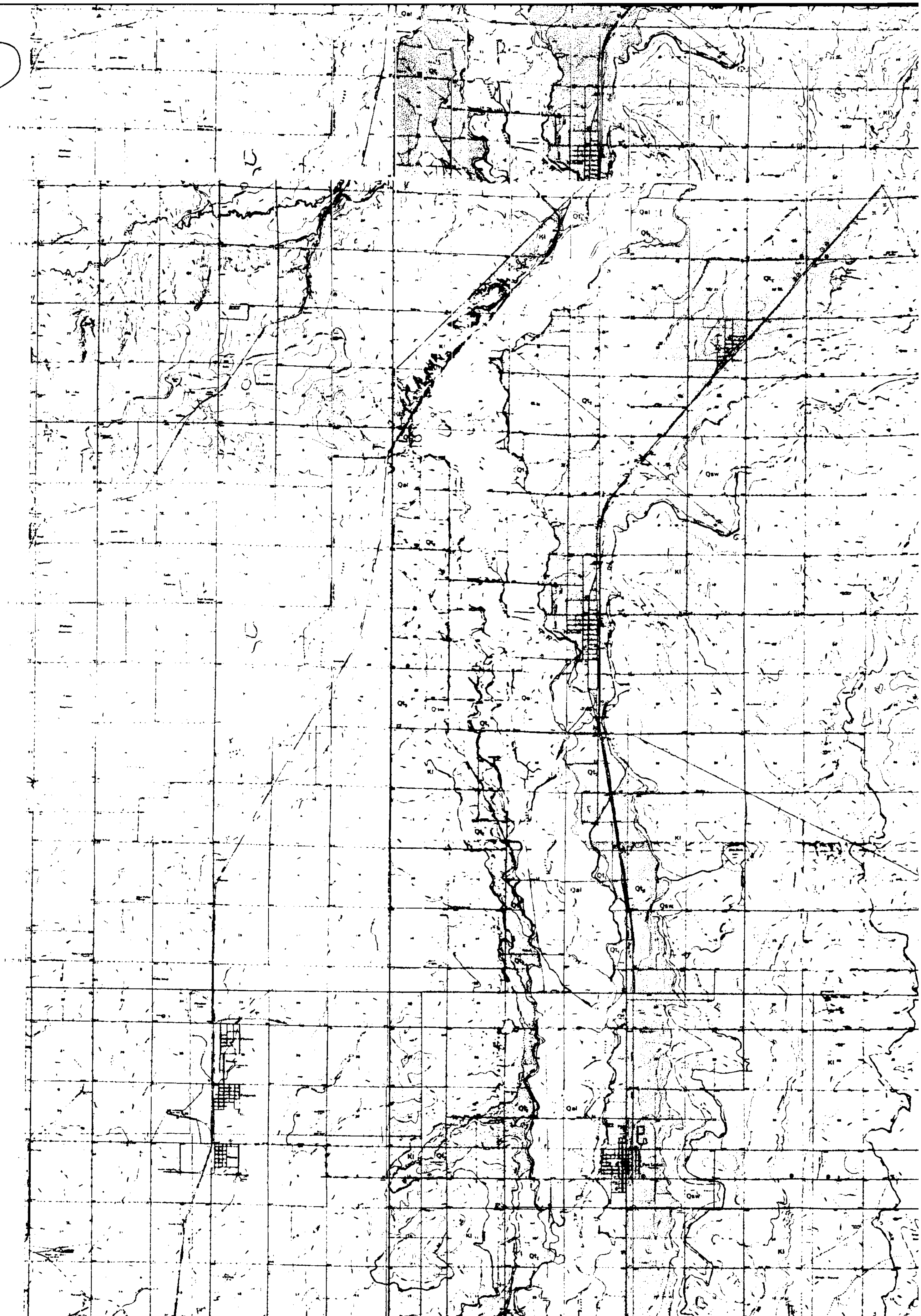

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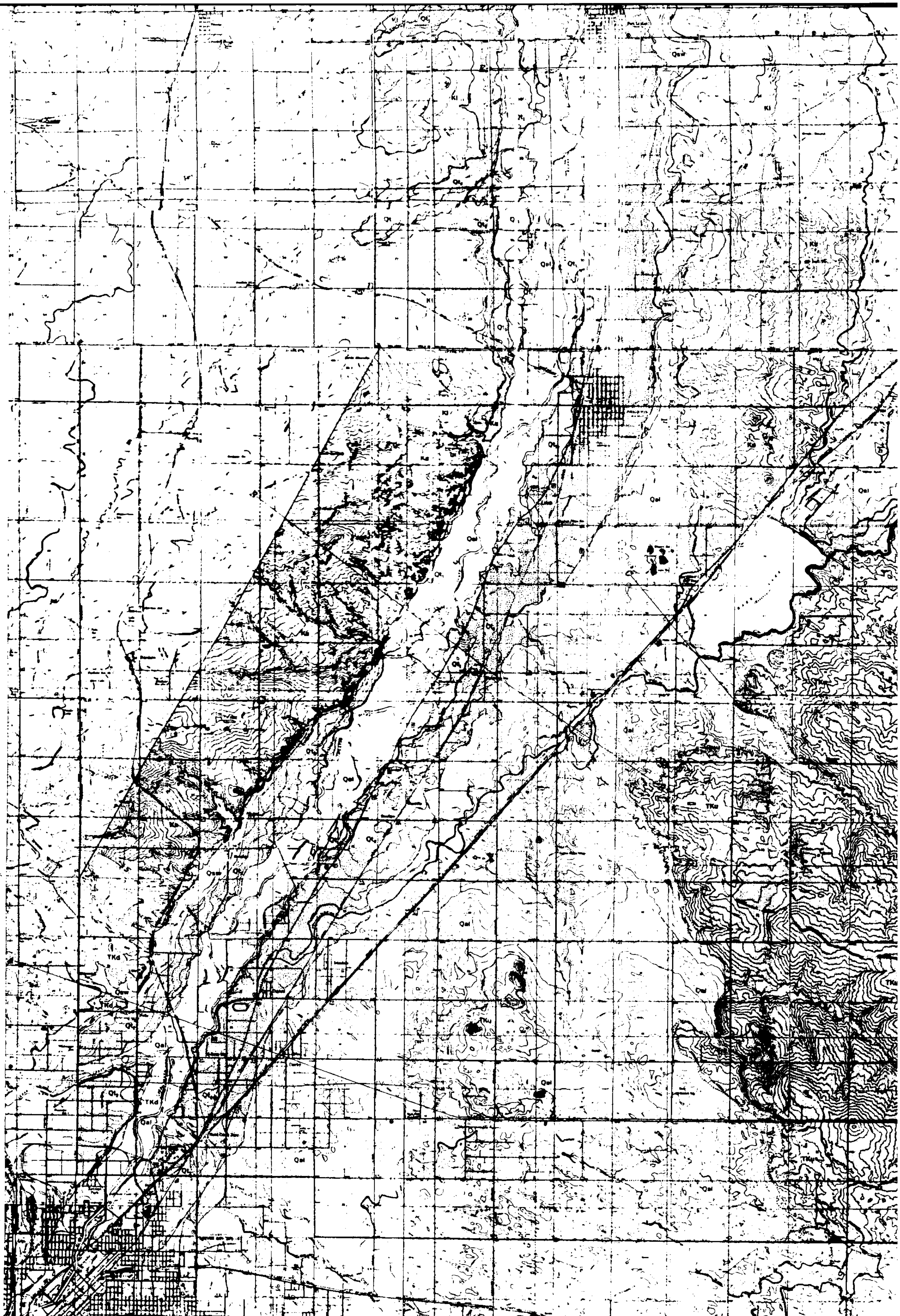

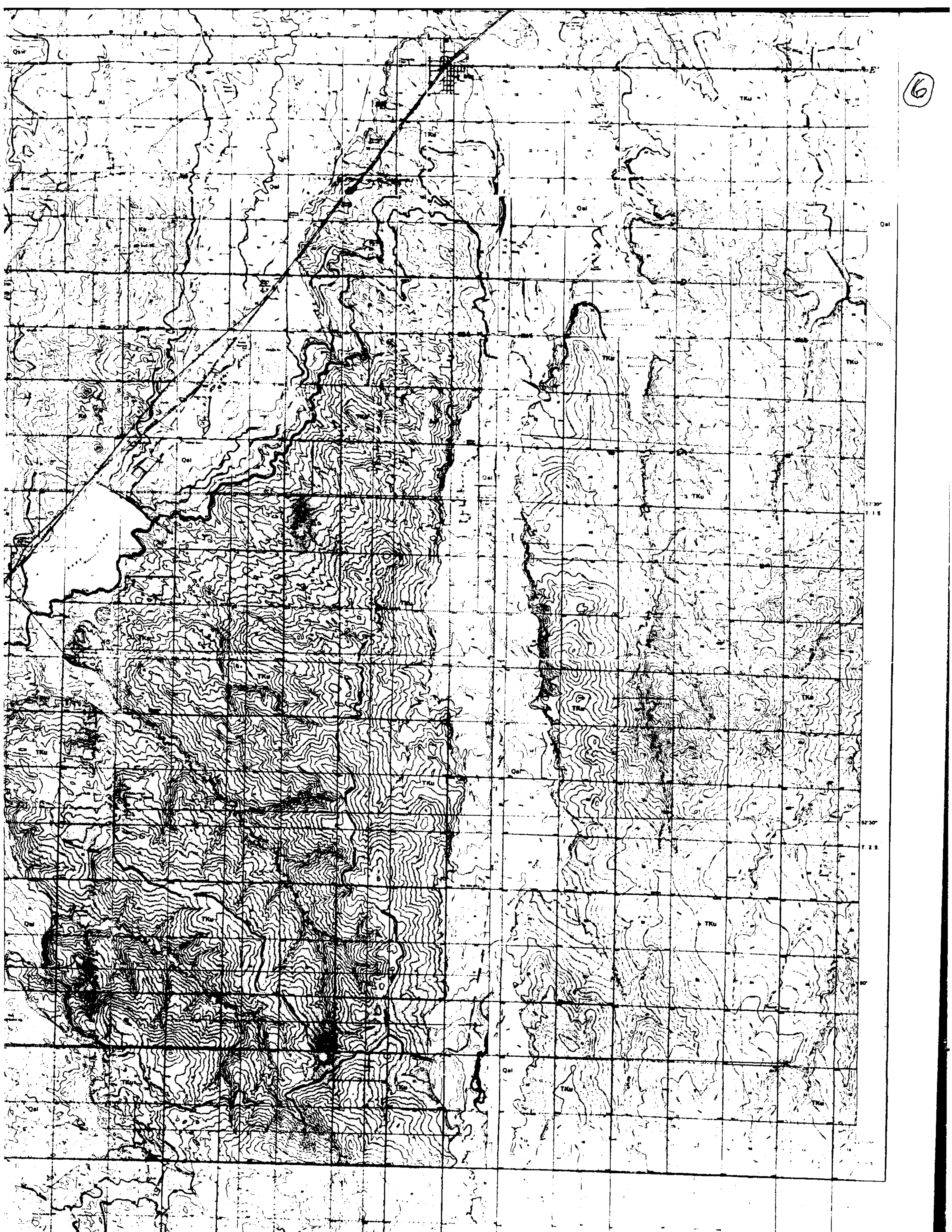

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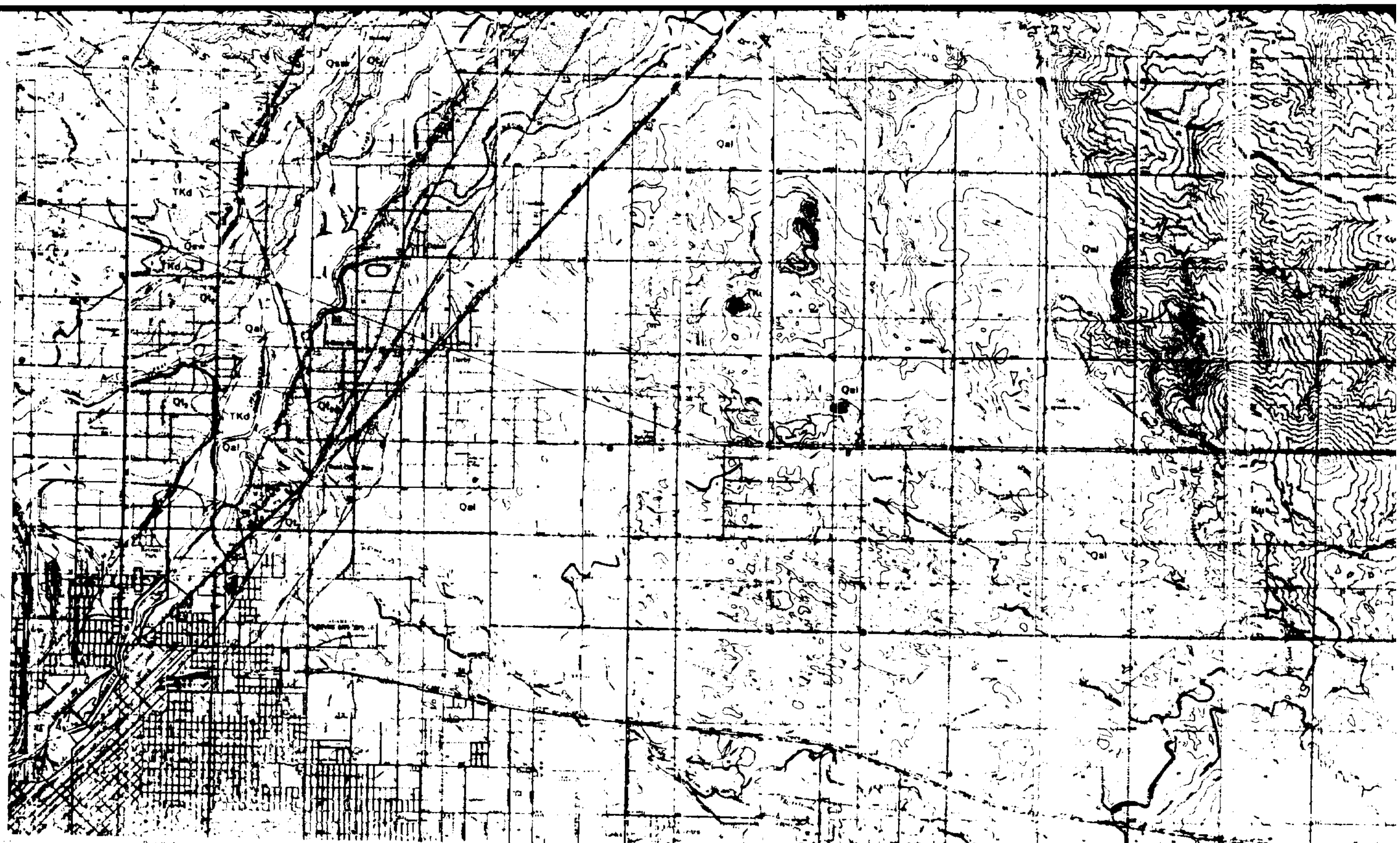
T. 1 S.
T. 2 S.

D



Base from U.S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND
SHOWING AREAL GEOLOGY AND LOCATION OF

SCALE 1:63360

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

(8)

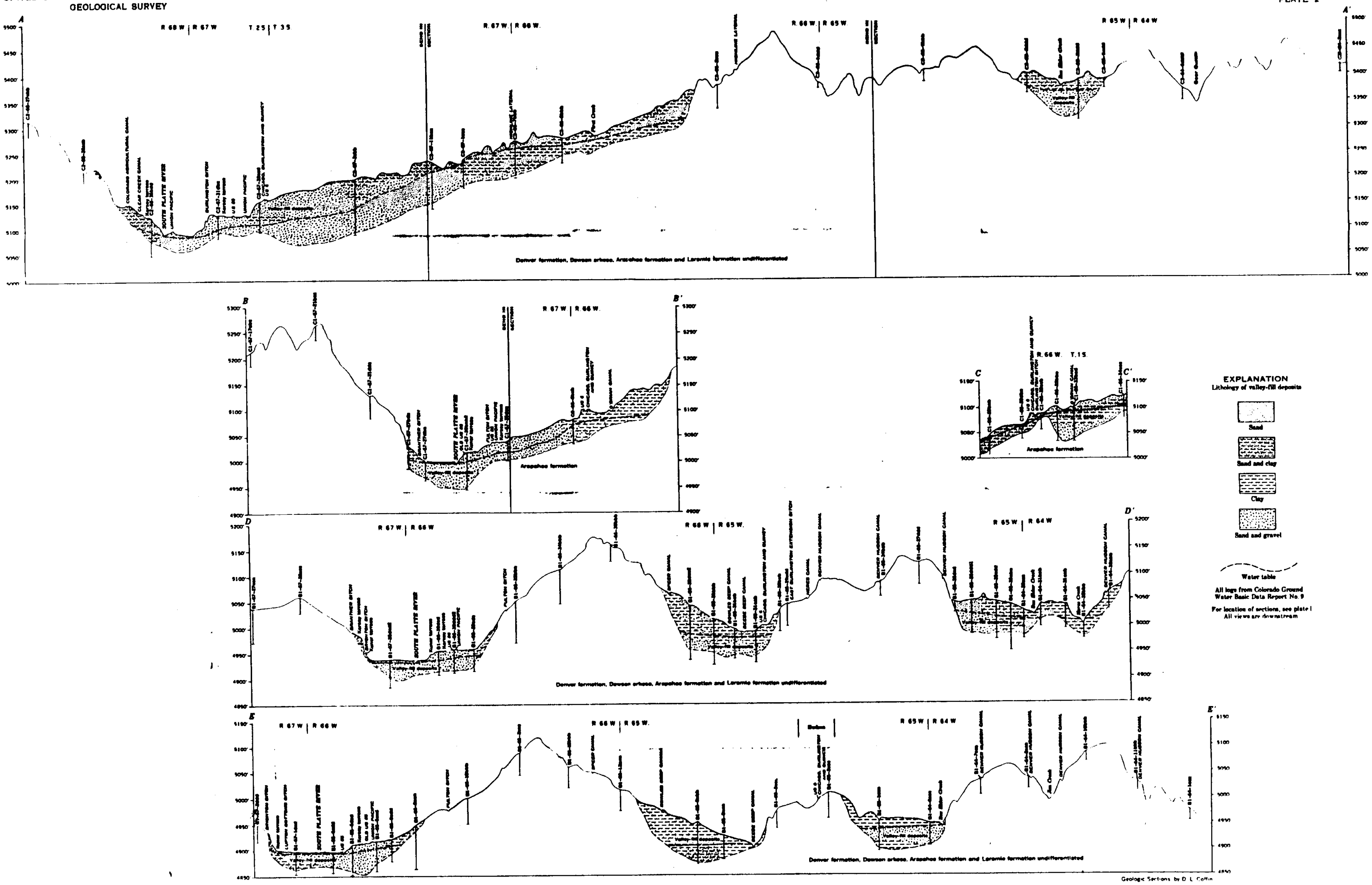
IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
OLOGY AND LOCATION OF GEOLOGIC SECTIONS

SCALE 1:63360

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

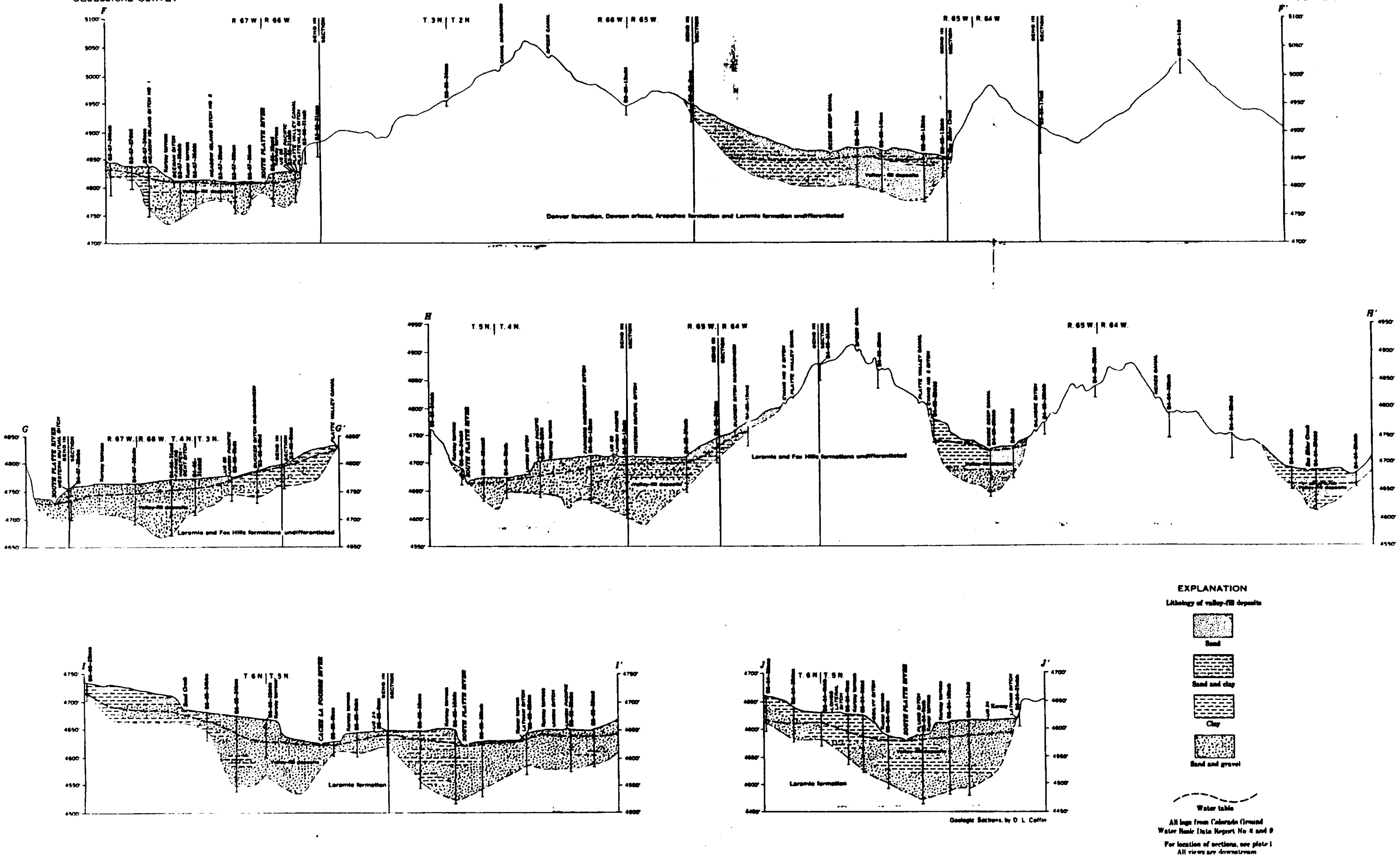
Geology compiled primarily from aerial photographs but modified in part from geologic maps by Emmons, Cross and Eldridge (1896) and Hunt

84324 RC2



GEOLOGIC SECTIONS ALONG LINES A-A' THROUGH E-E' OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO

S 4324 RCZ



GEOLOGIC SECTIONS ALONG LINES F-F' THROUGH J-J' OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO

DATUM IS MEAN SEA LEVEL

S.1324 RCD

(1)

EXPLANATION

• 4966

Test hole drilled for the U.S. Geological Survey

Number is altitude of top of bedrock, in feet

○ 5032

Well or test hole

Number is altitude of top of bedrock feet. Based on driller's log

-○- 5187

Well or test hole

Number is inferred altitude of top of bedrock, in feet Based on depth of well, which is presumed to end at top of bedrock

5200

Contours on top of bedrock, in feet above mean sea level

Based on test-hole and well data. Contour interval 20 feet. Dashed where approximately located

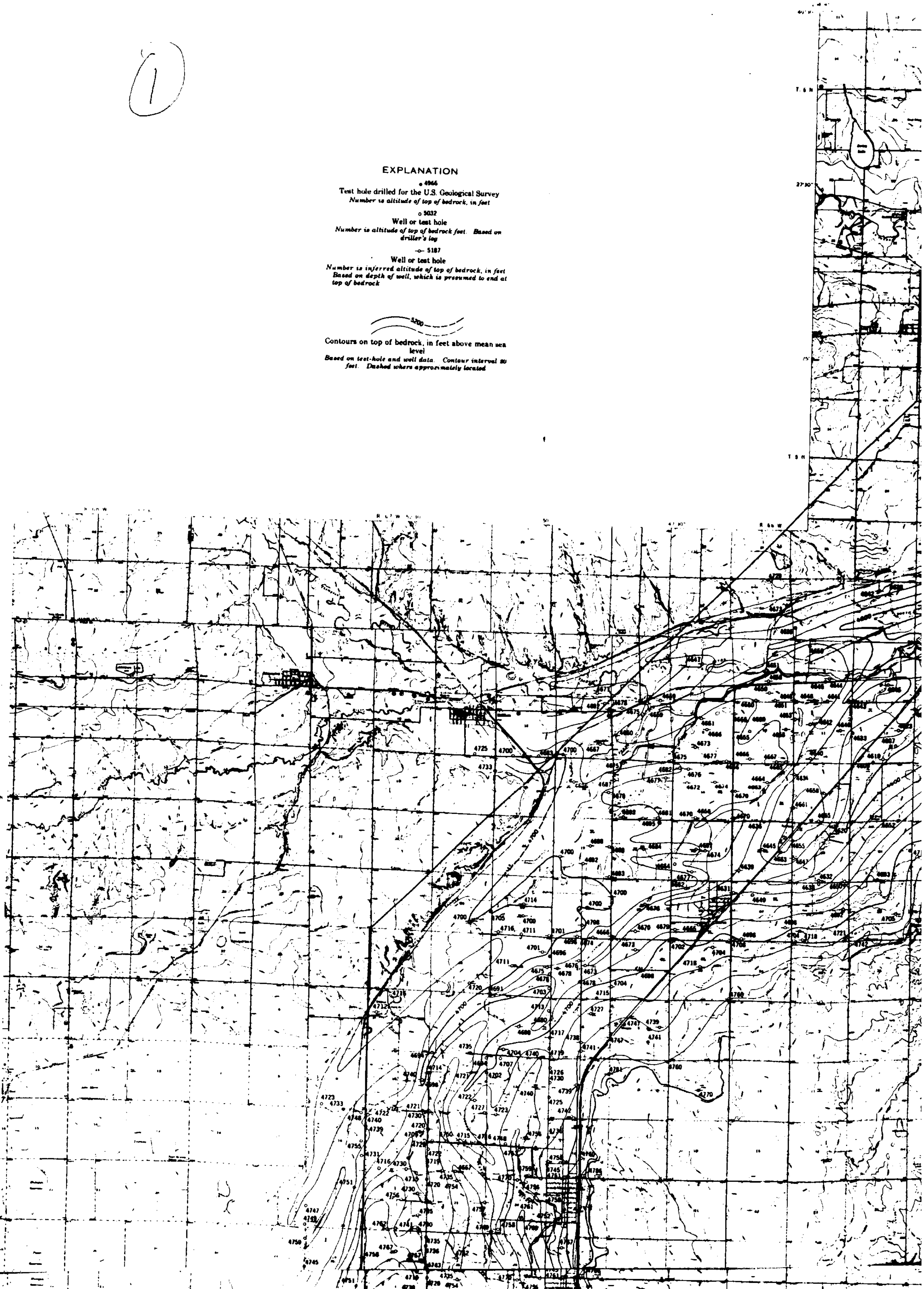
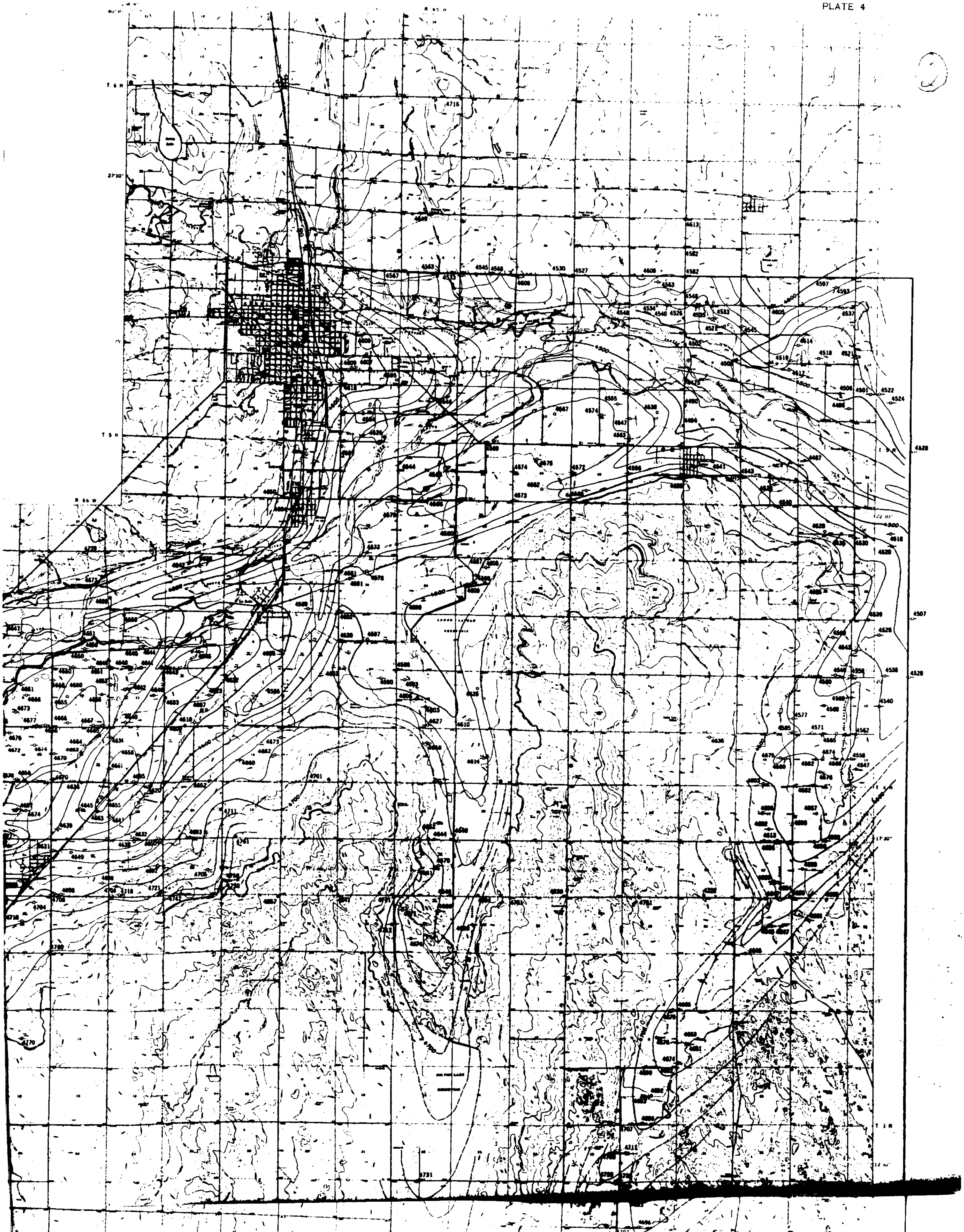
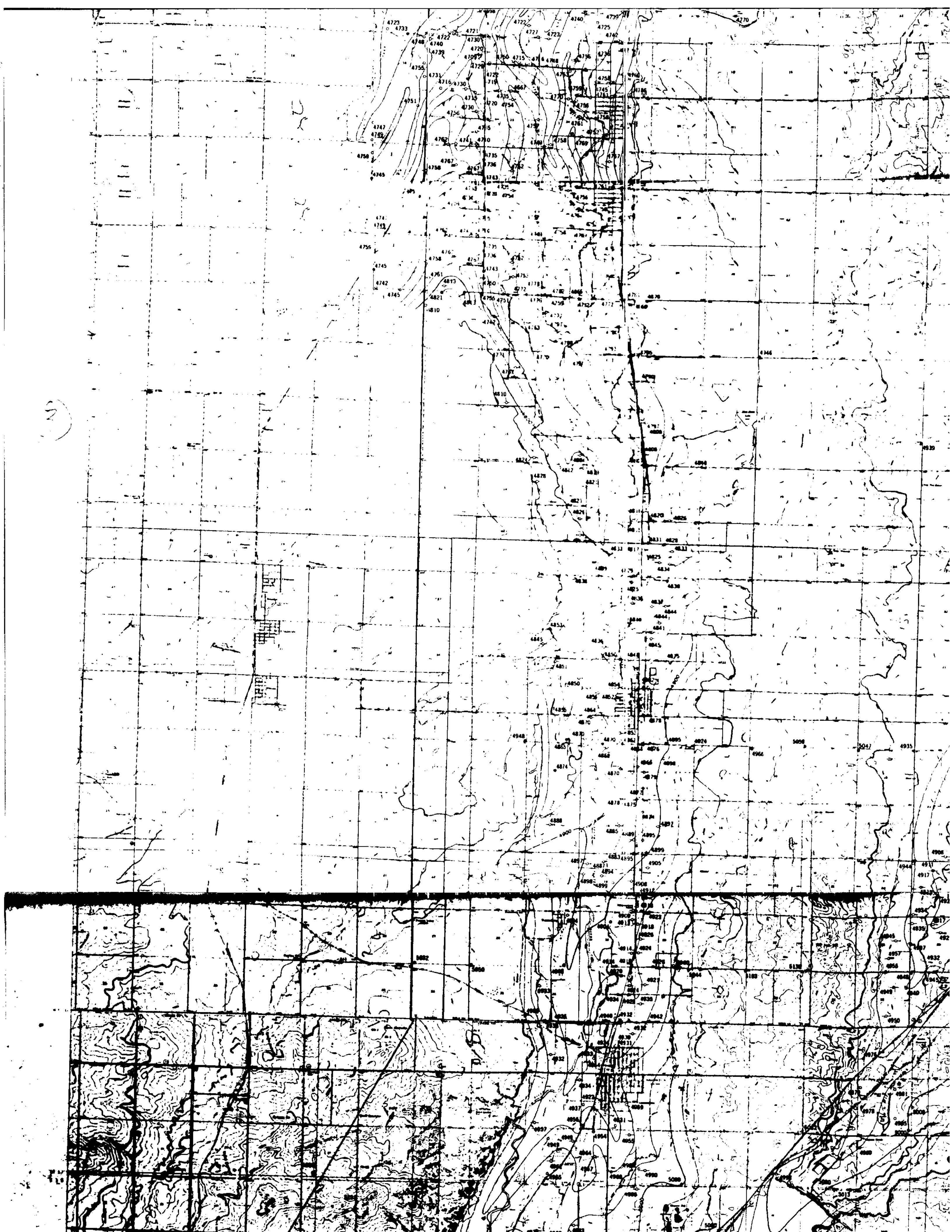
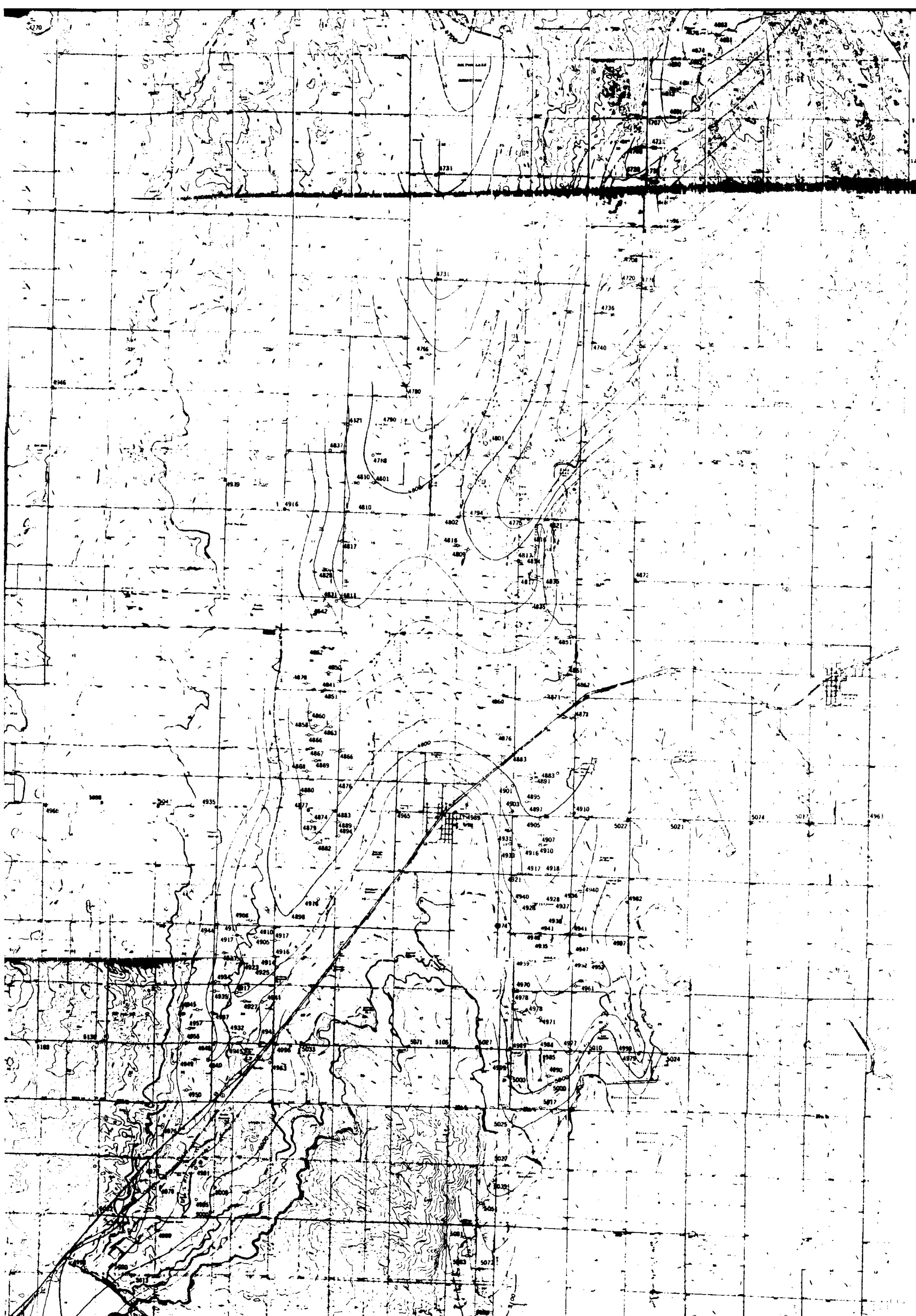


PLATE 4







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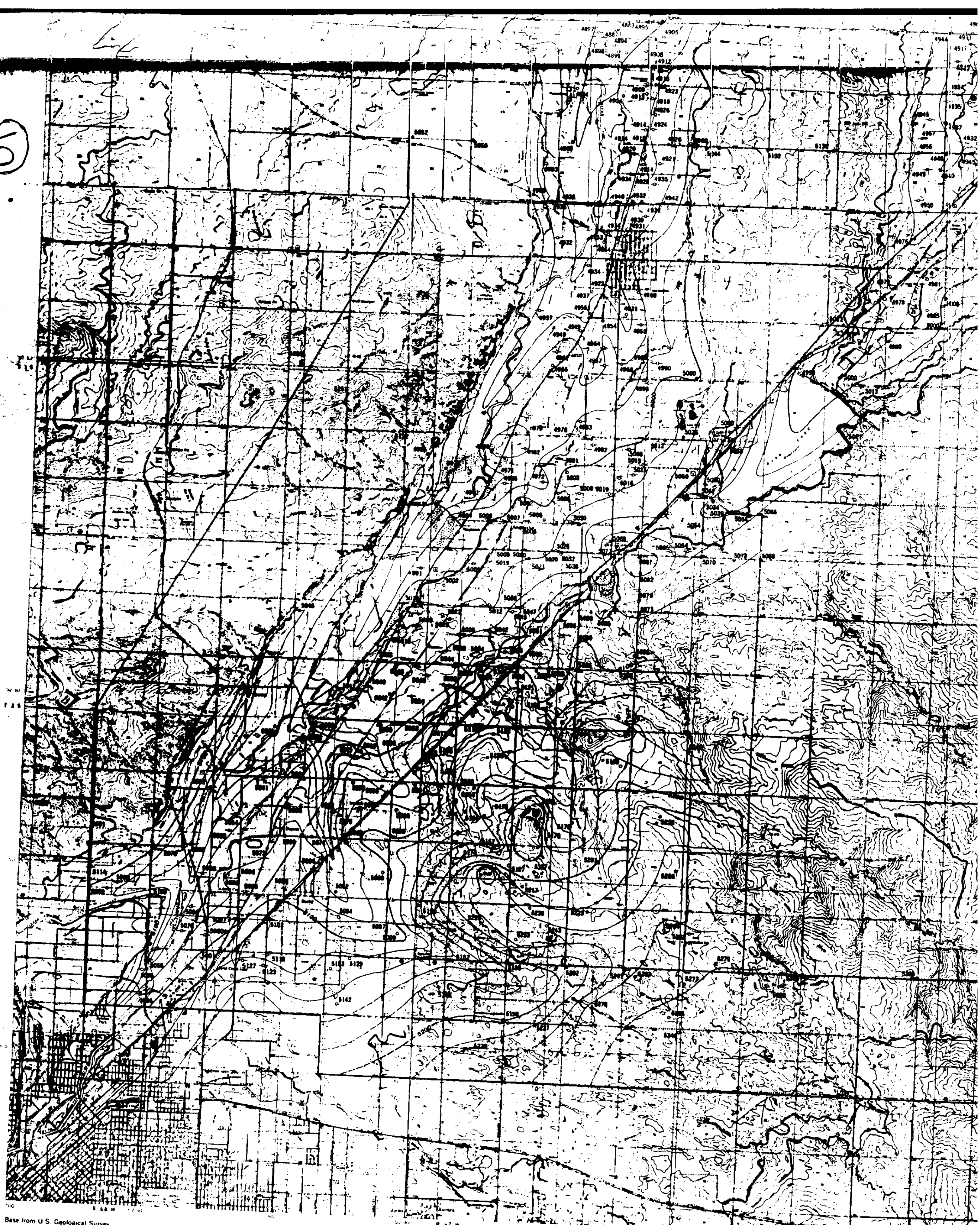
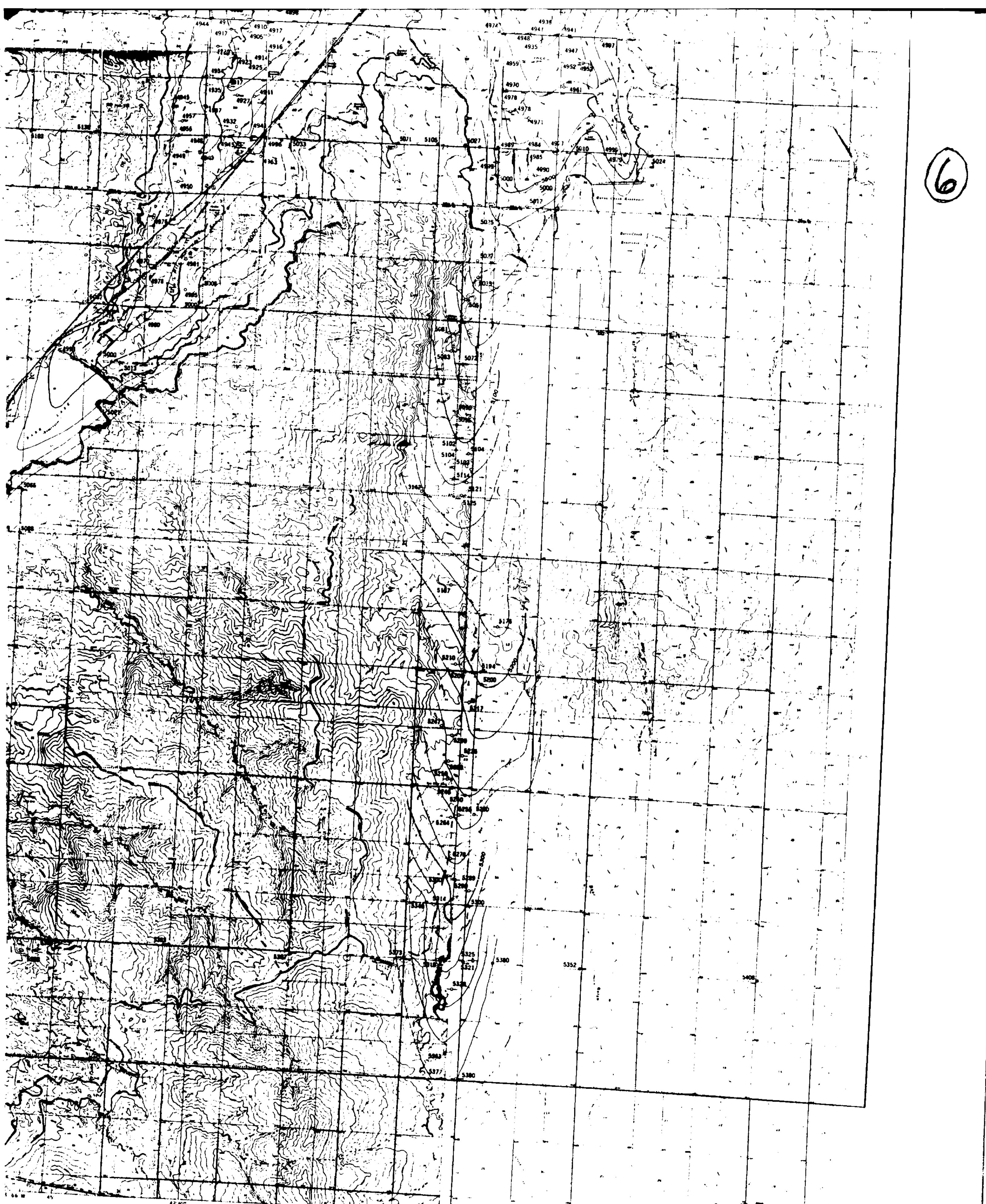


Base from U.S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWE
SHOWING THE CONFIGURATION OF THE BEDROCK



(6)

ERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
RATION OF THE BEDROCK SURFACE

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.

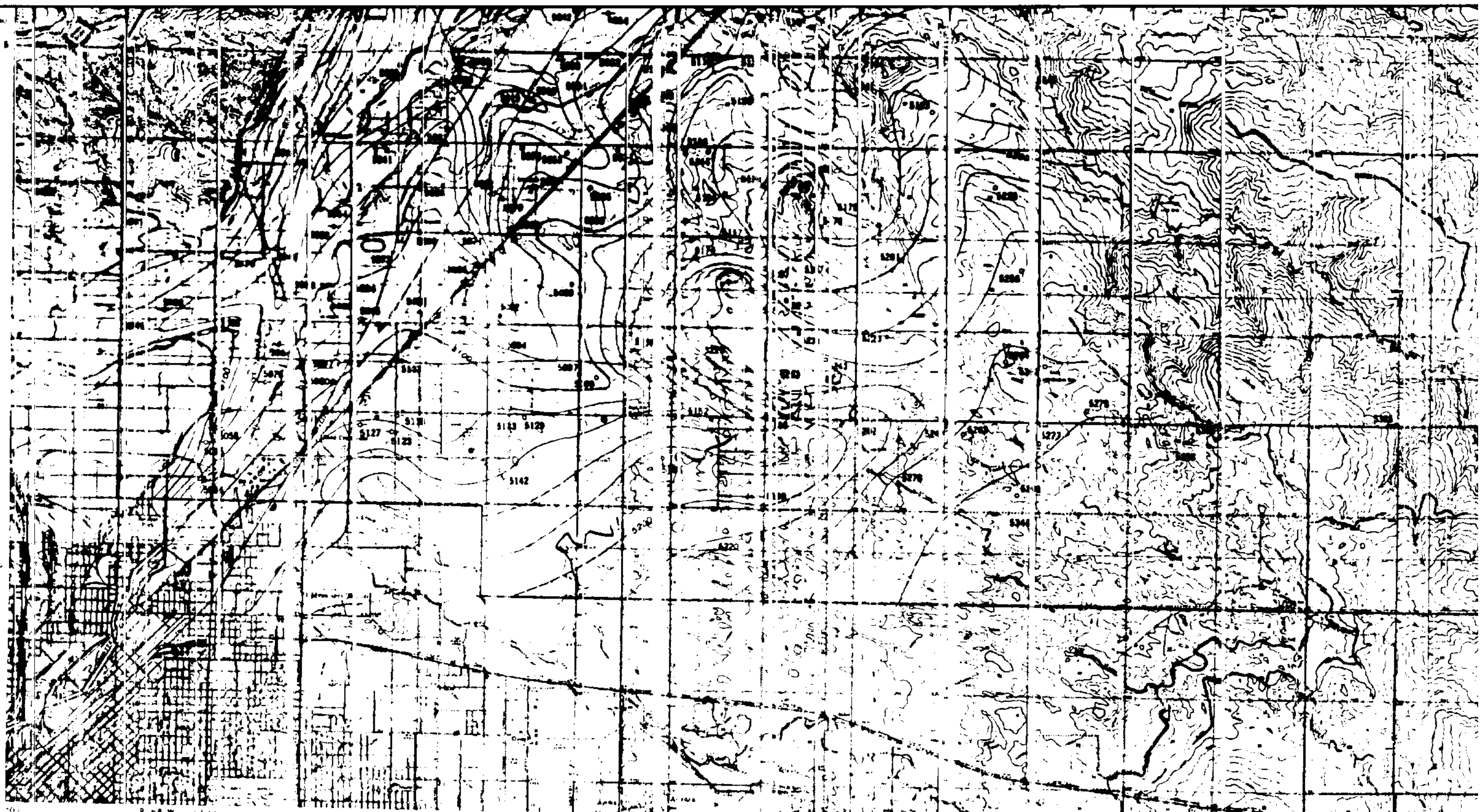
Configuration of the Bedrock Surface, by H. E. McGovern

SCALE 1:63 360

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

84324 R02

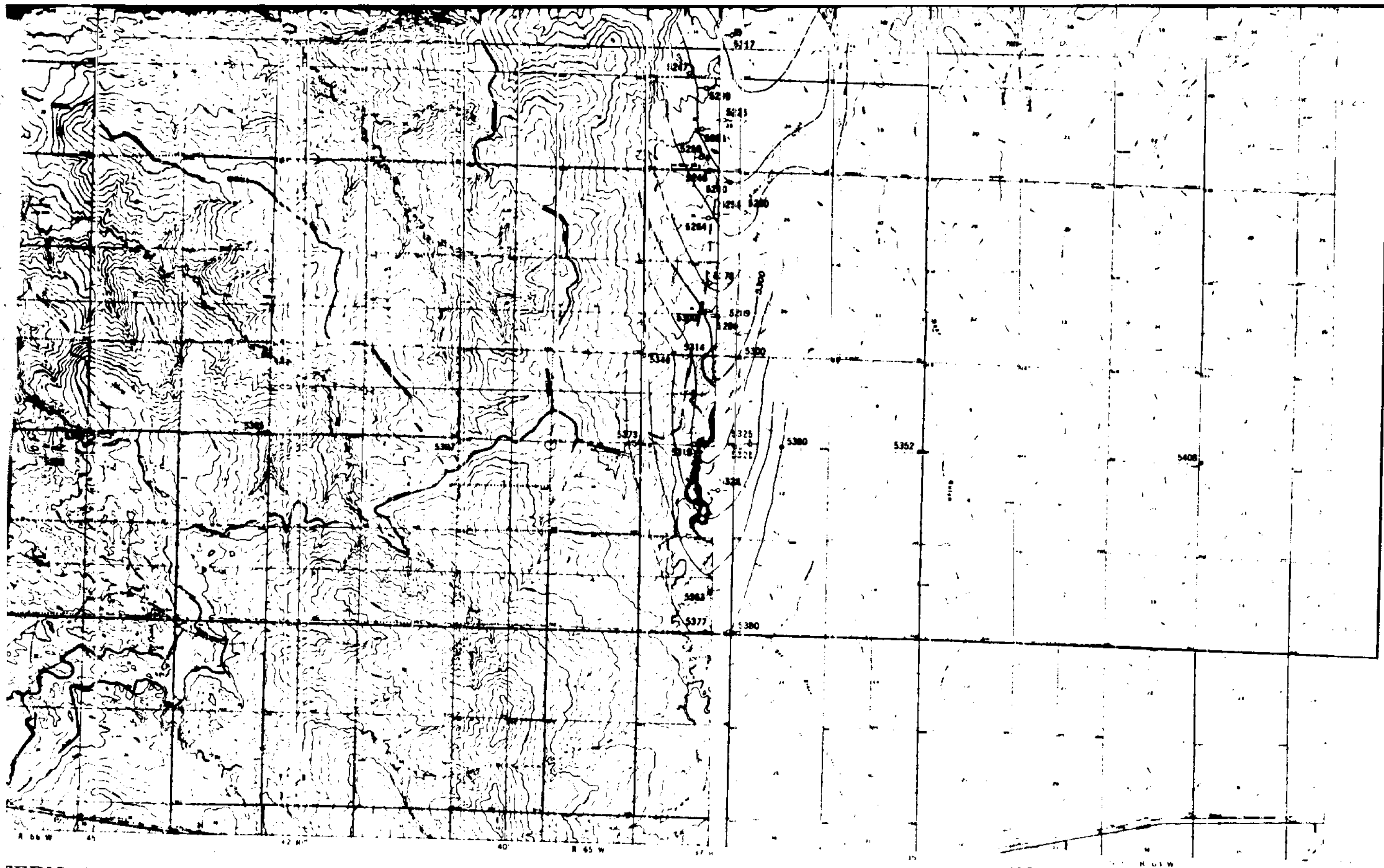
7



Base from U.S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHW
SHOWING THE CONFIGURATION OF THE BEDROCK

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL



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TERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
JRATION OF THE BEDROCK SURFACE

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

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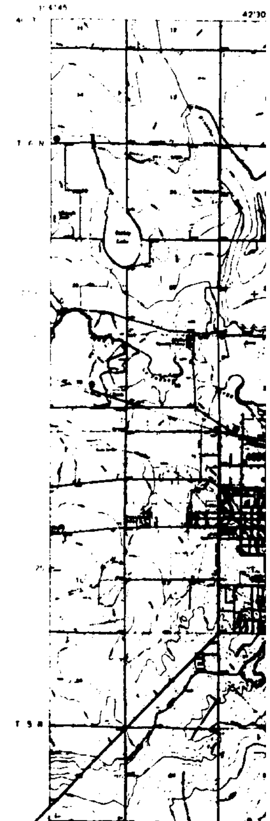
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

(1)



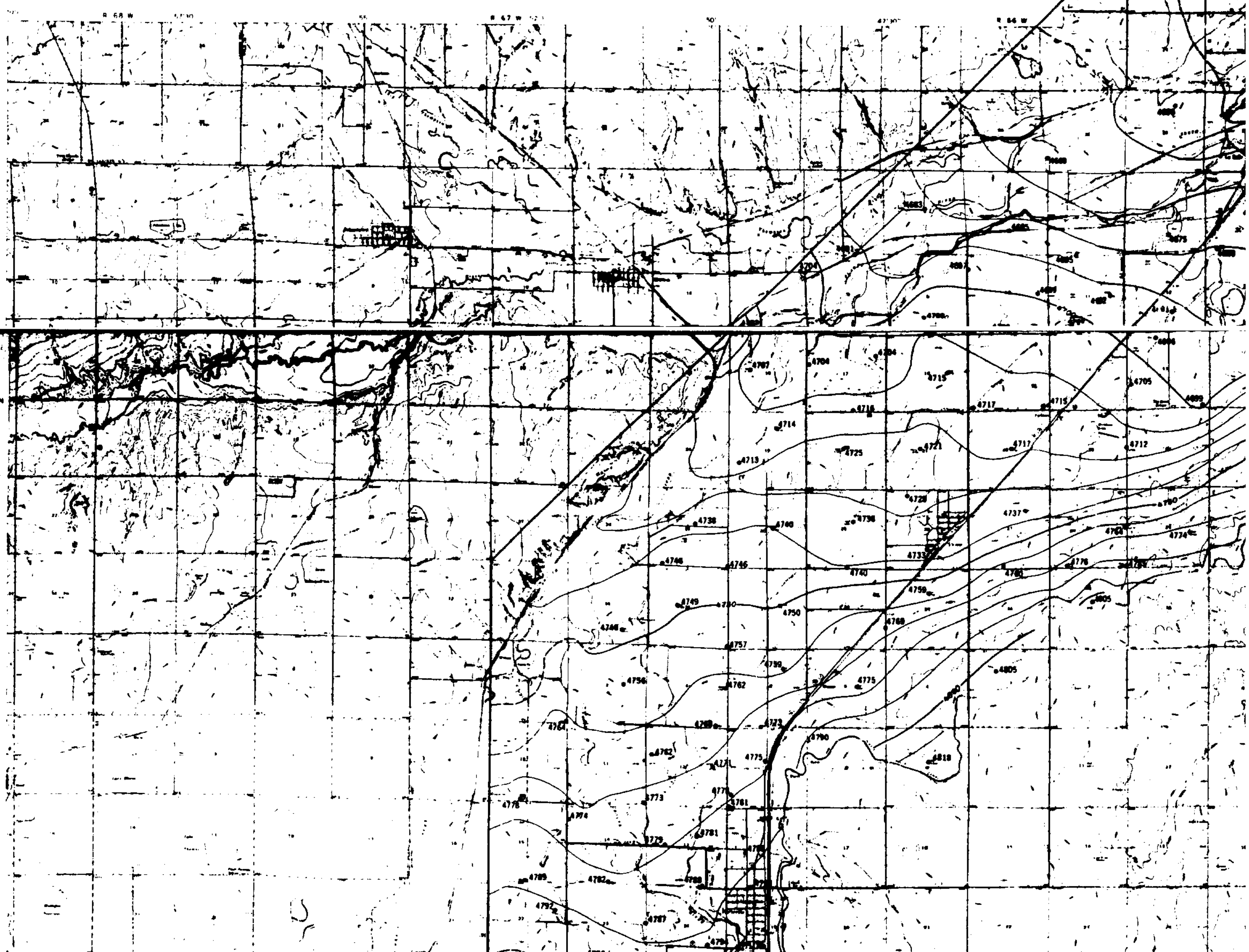
EXPLANATION

•4707
Well measured by the U.S. Geological Survey in Novemeber 1957
Number is altitude of water level, in feet

○5185
Well measured by the U.S. Army Chemical Corps in November 1957
Number is altitude of water level, in feet

4950

Contours on water table, in feet above mean sea level
Dashed where approximately located, dotted where inferred. Contour interval 10 feet



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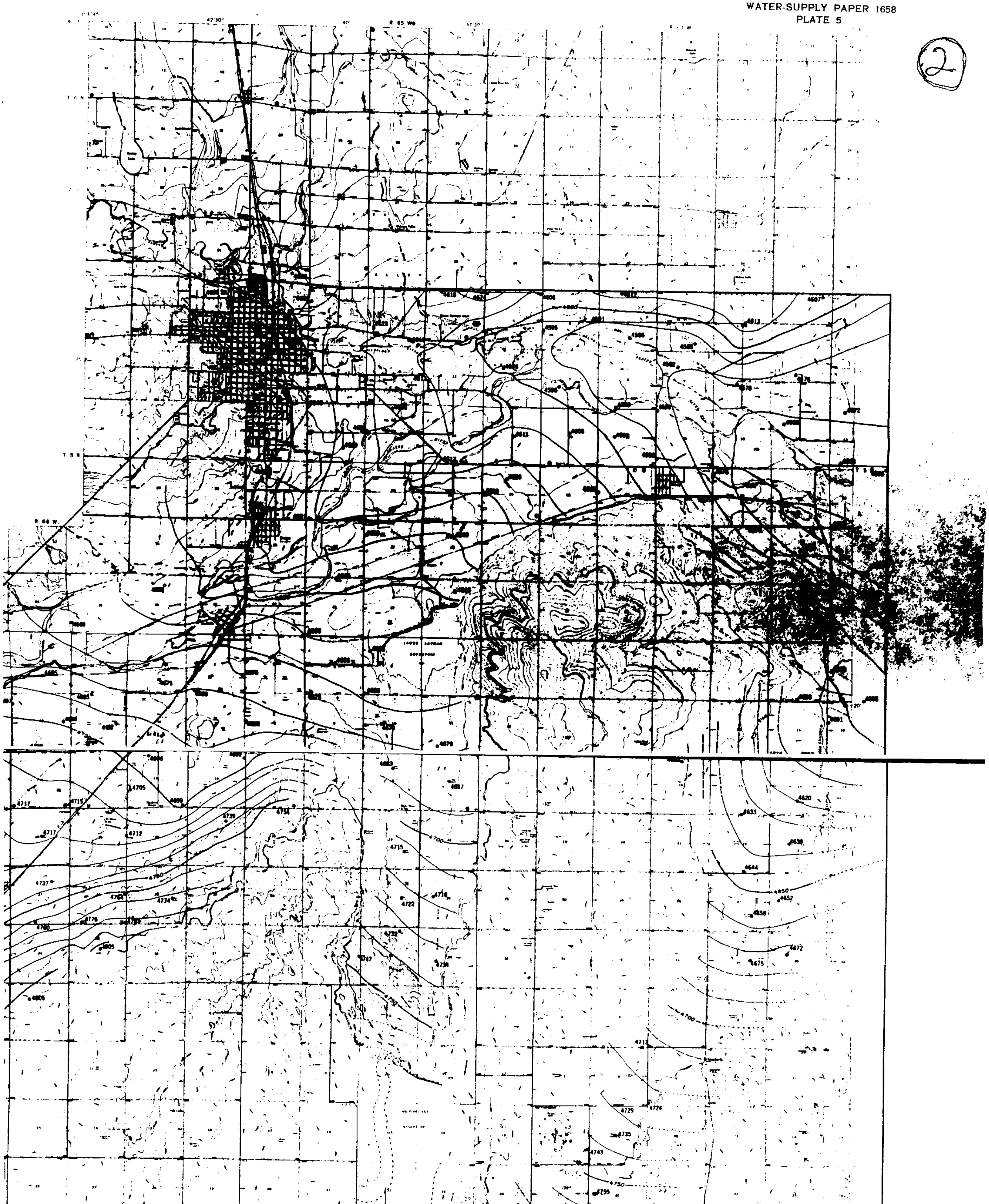

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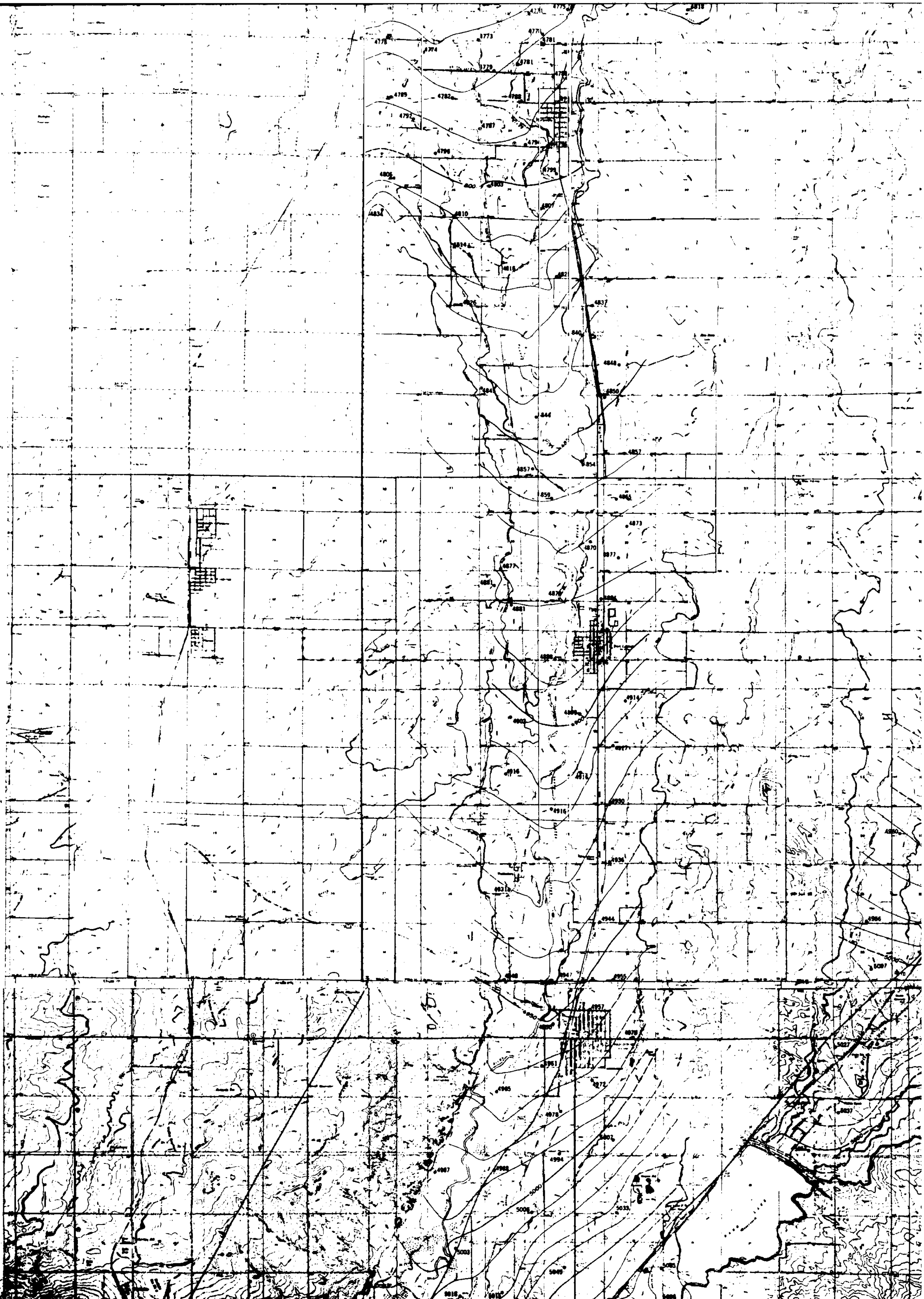

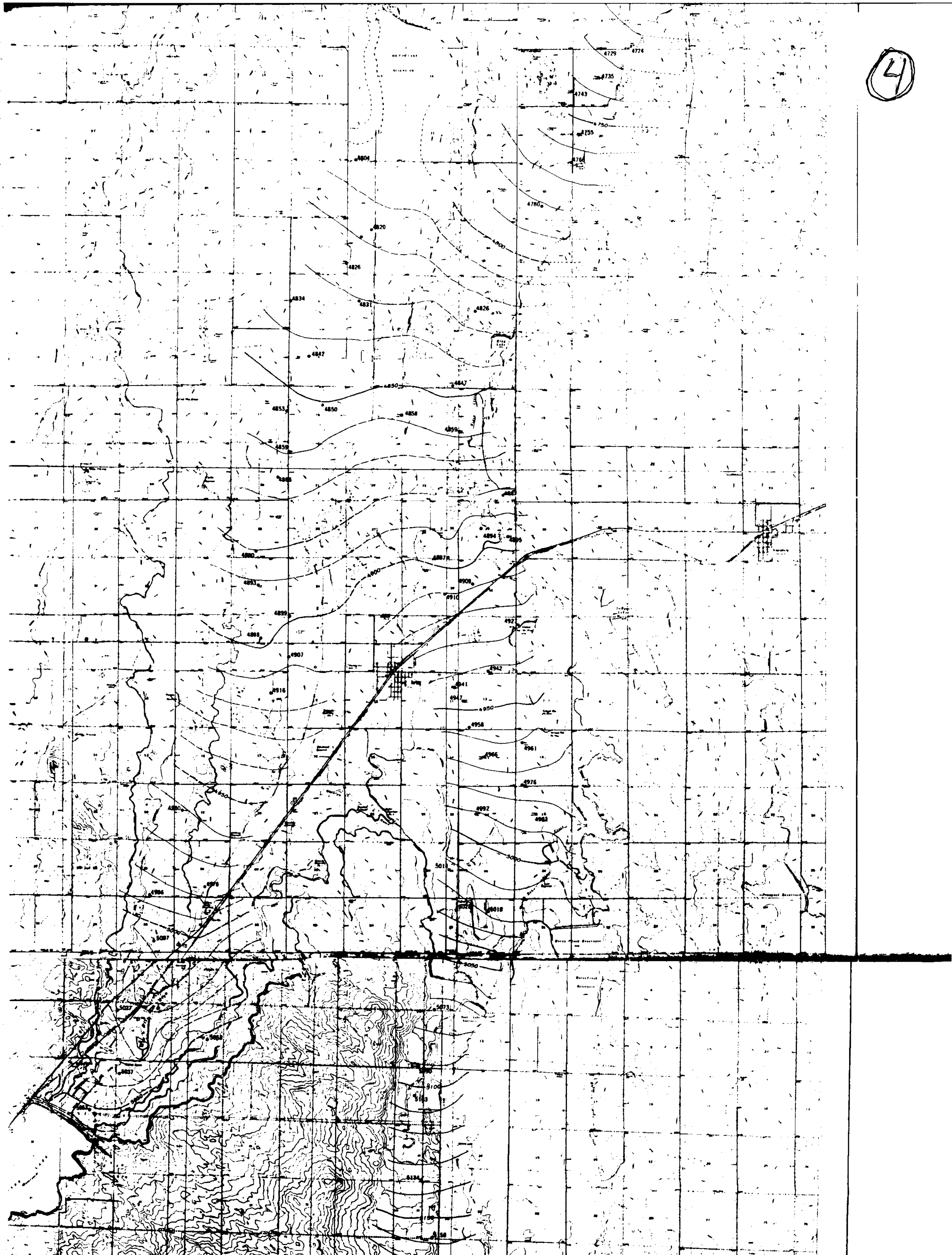

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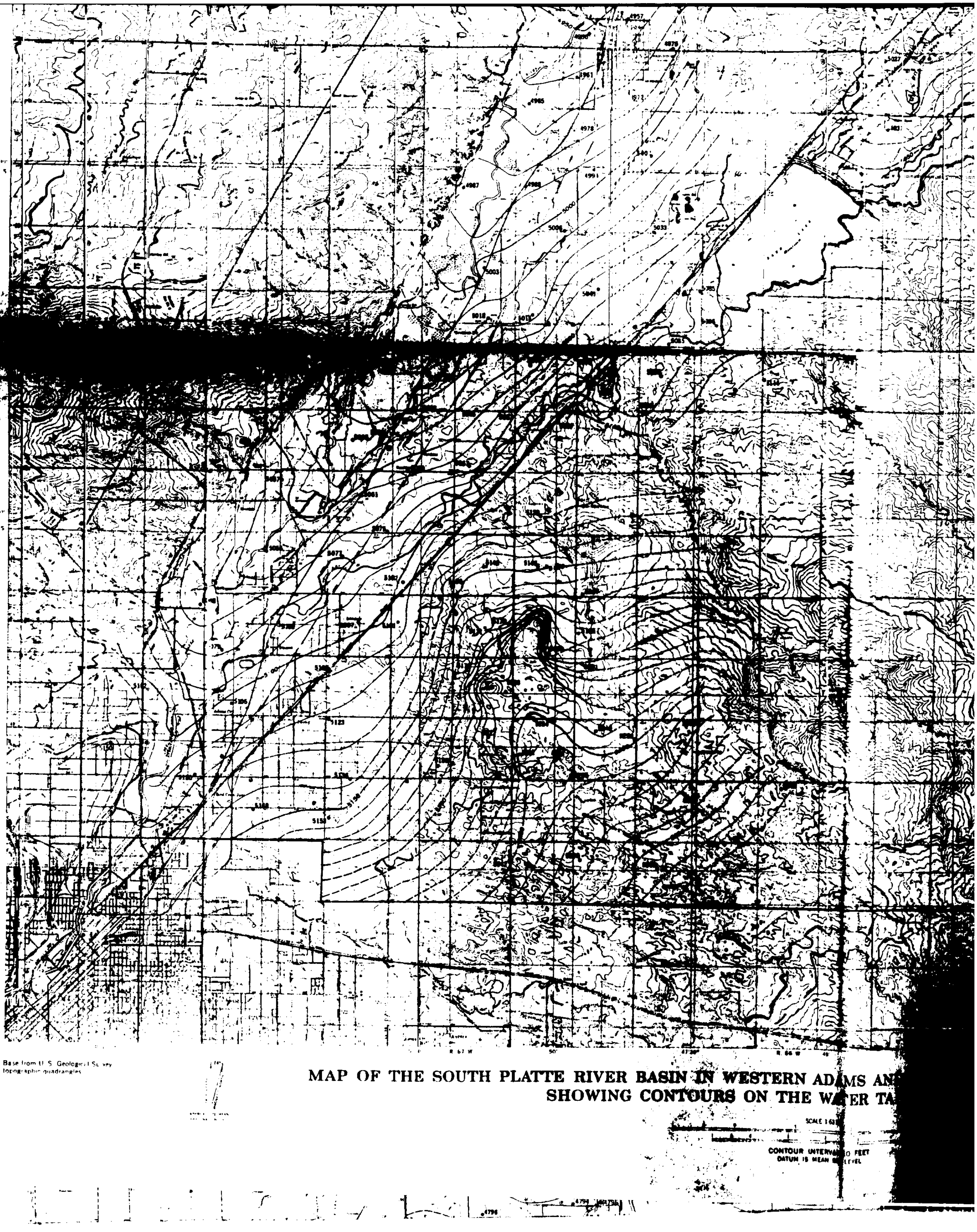

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AN
SHOWING CONTOURS ON THE WATER TA

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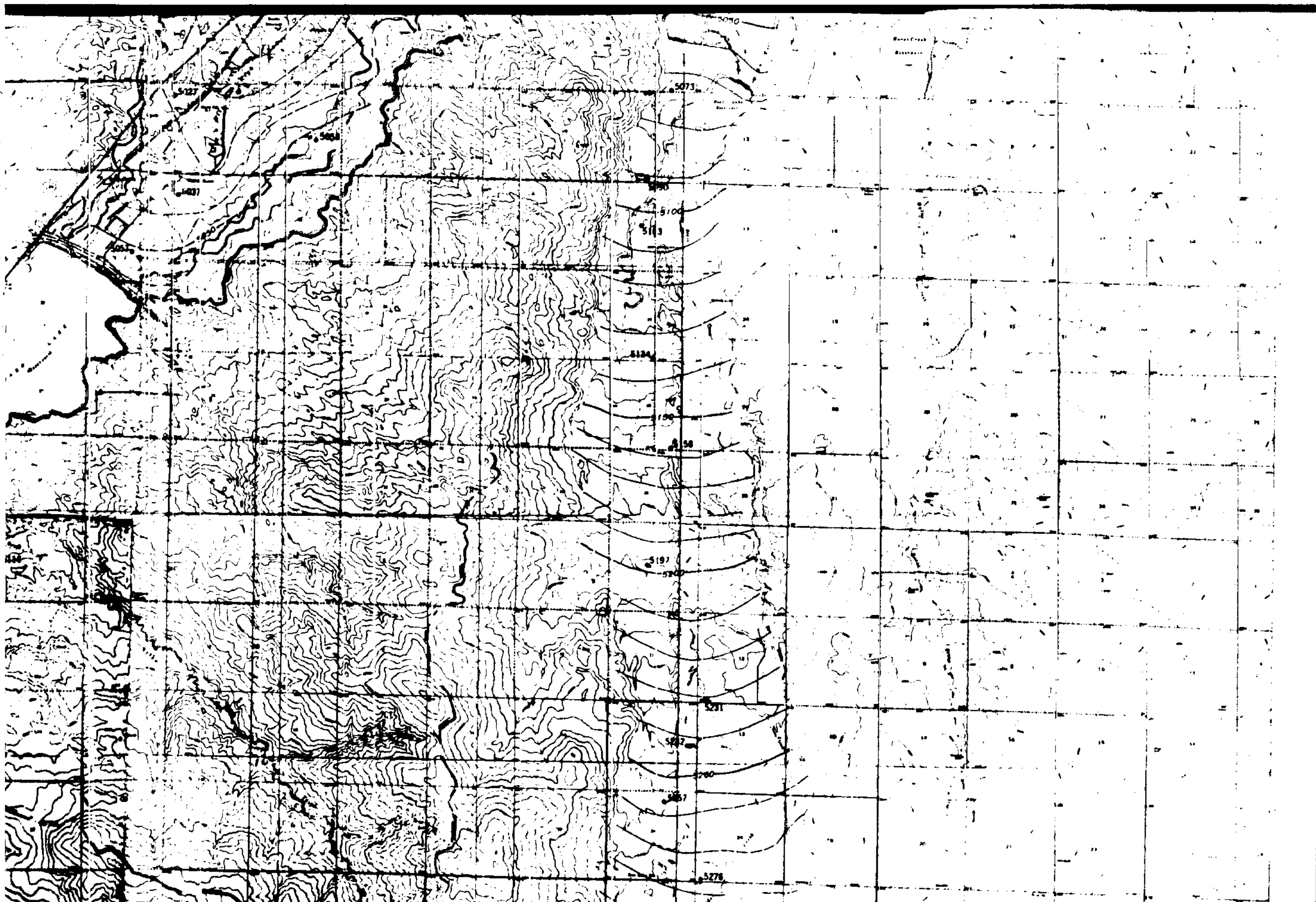

TERN ADAMS AN... COUNTIES, COLORADO
THE WATER TA...

SCALE 1:63...

CONTOUR INTERVAL ... FEET
DATUM IS MEAN ... LEVEL

Contours on the Water Table by ...

84324 R02

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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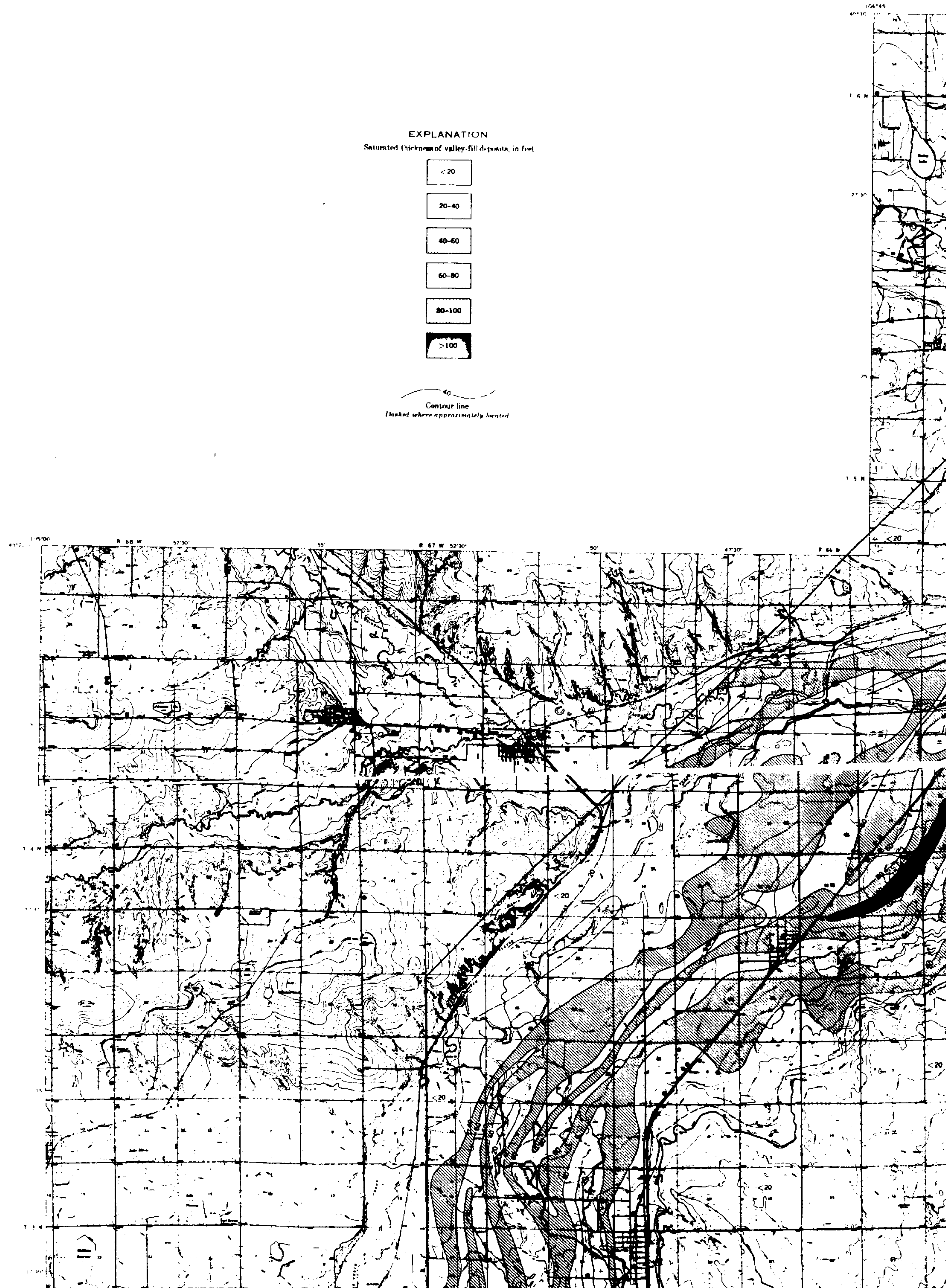

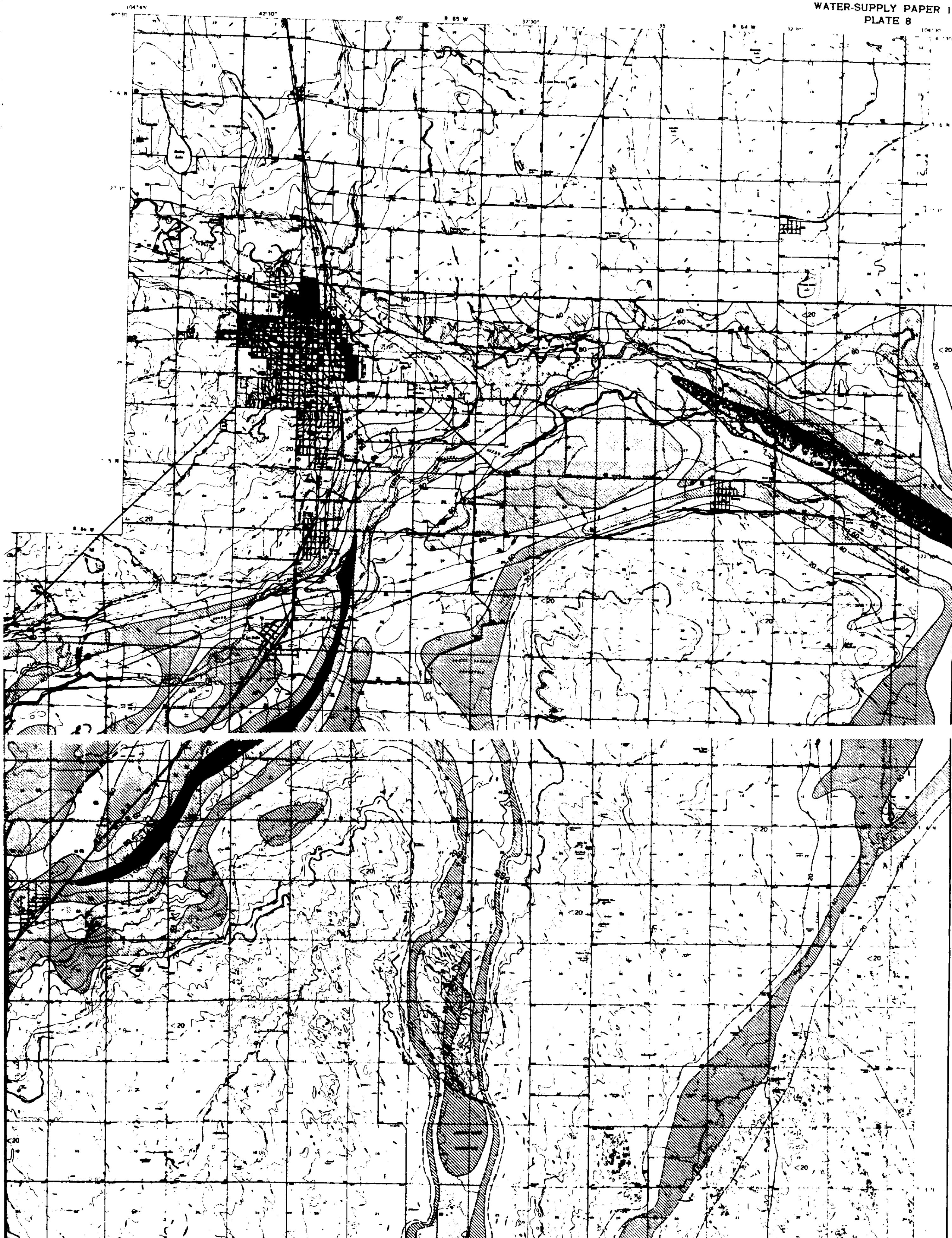

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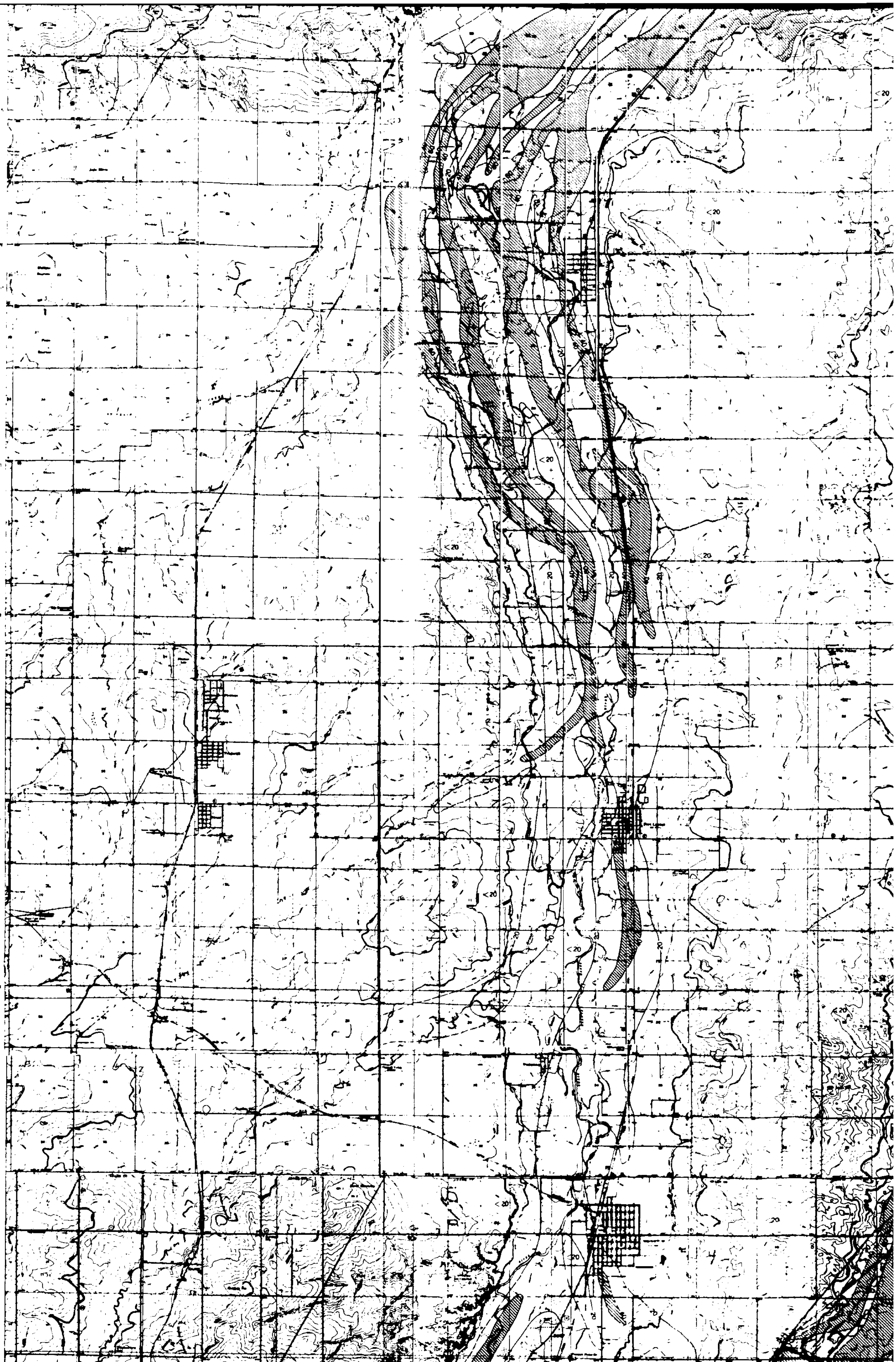

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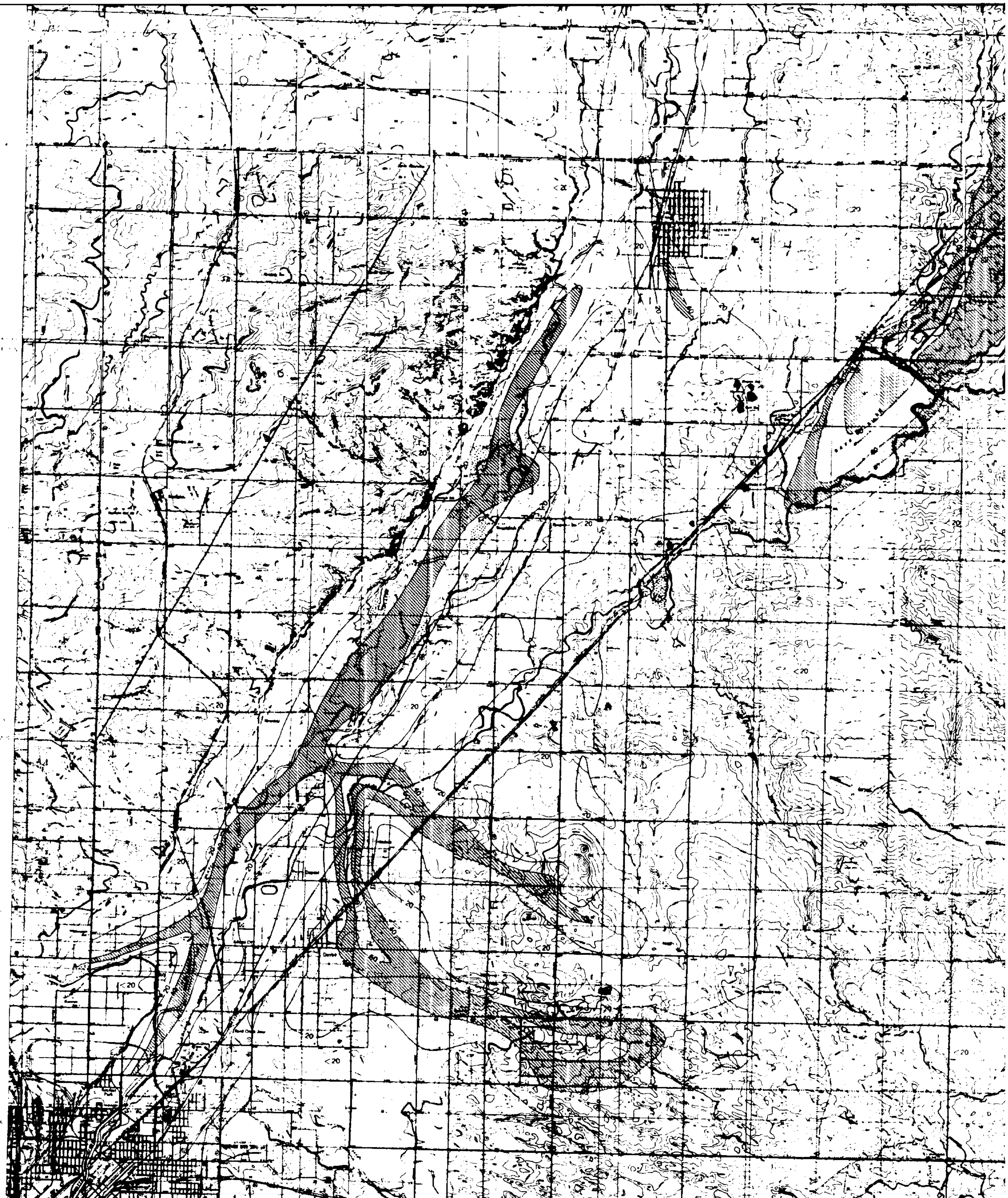
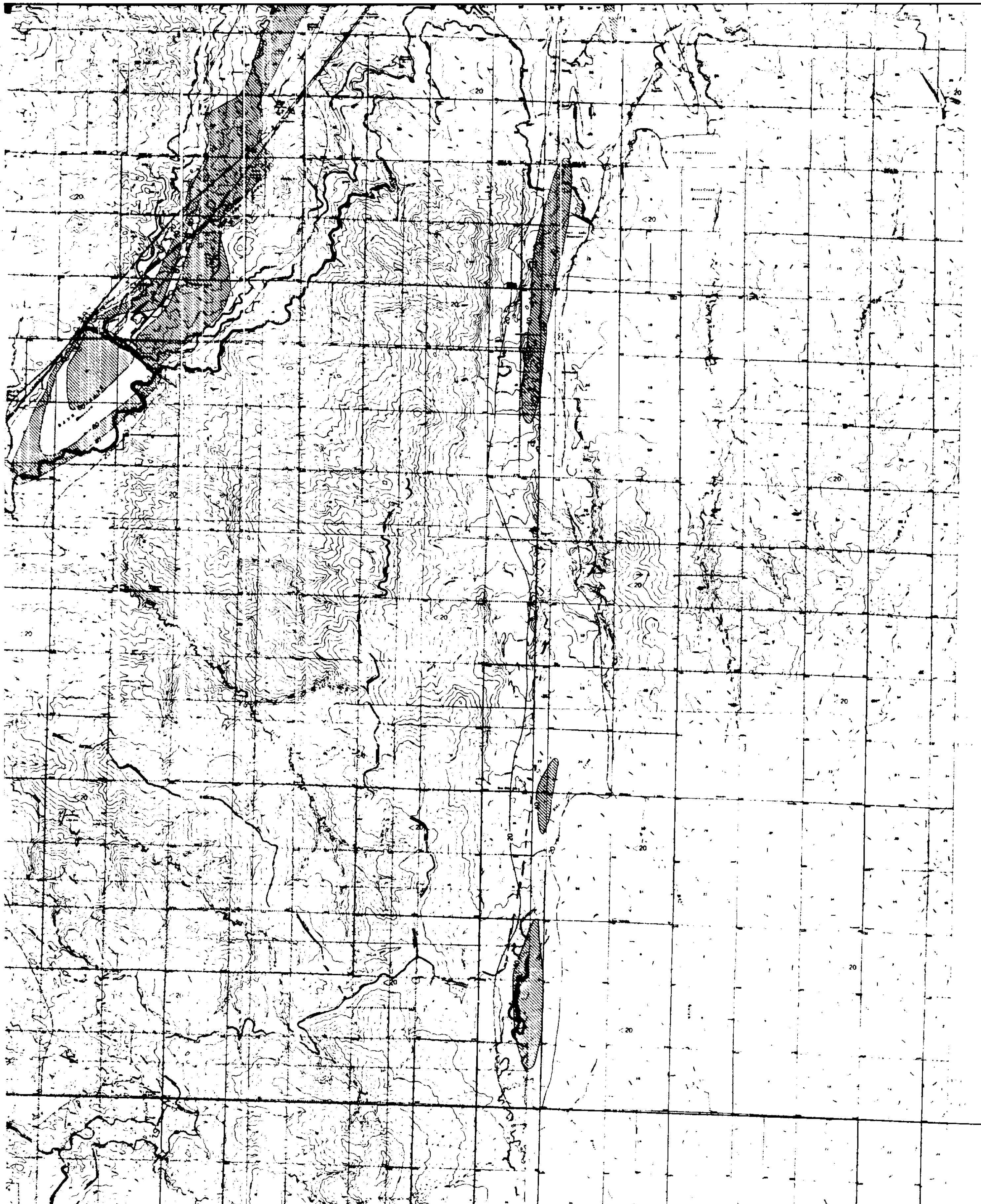


Base from U. S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND
SHOWING THE THICKNESS OF THE SATURATED

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

6



WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
SS OF THE SATURATED VALLEY-FILL DEPOSITS

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

Geology compiled primarily from aerial photographs but modified in part from geologic maps

84324 R02

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

1

EXPLANATION

•10

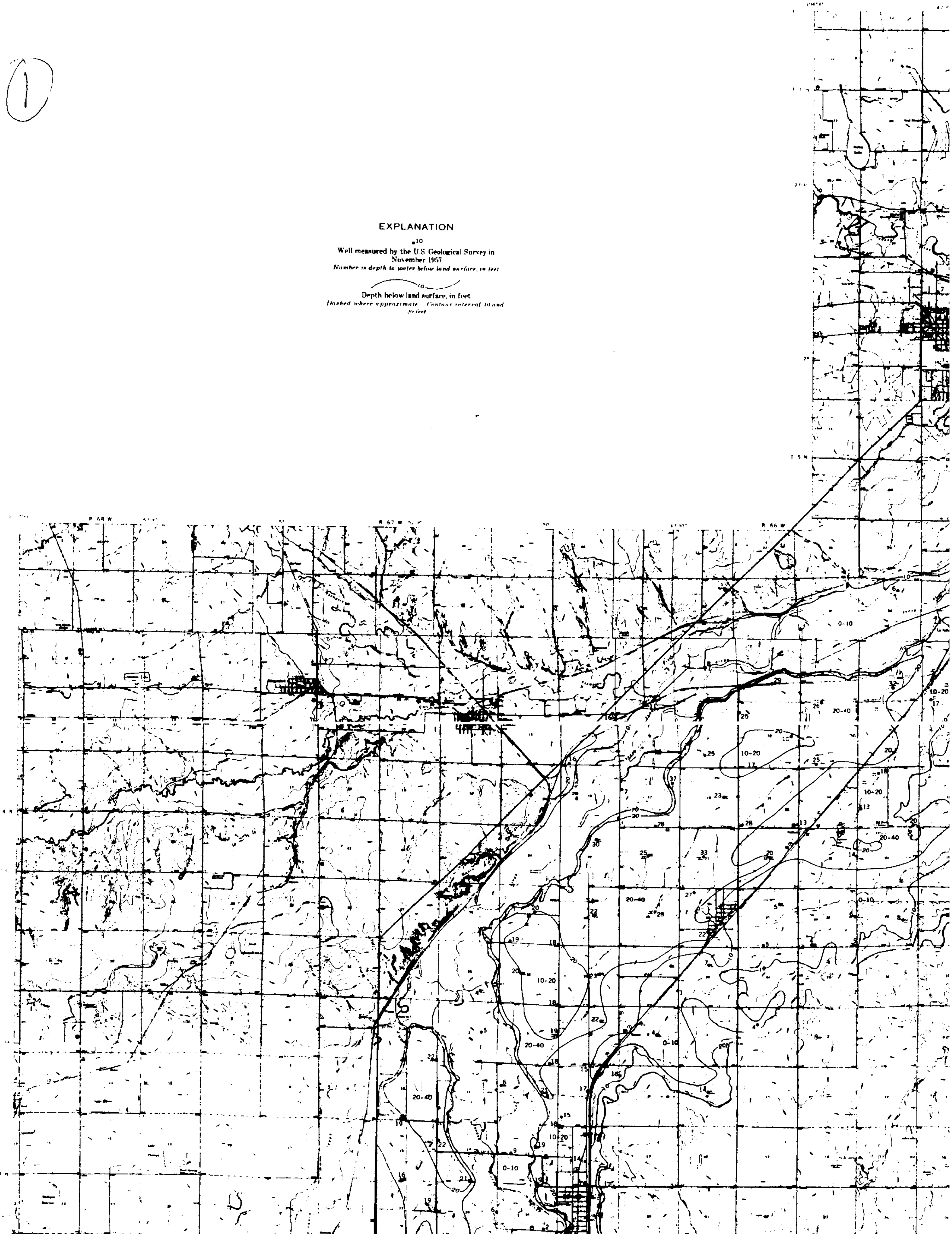
Well measured by the U.S. Geological Survey in November 1957

Number is depth to water below land surface, in feet

10

Depth below land surface, in feet

Dashed where approximate. Contour interval 10 and 20 feet



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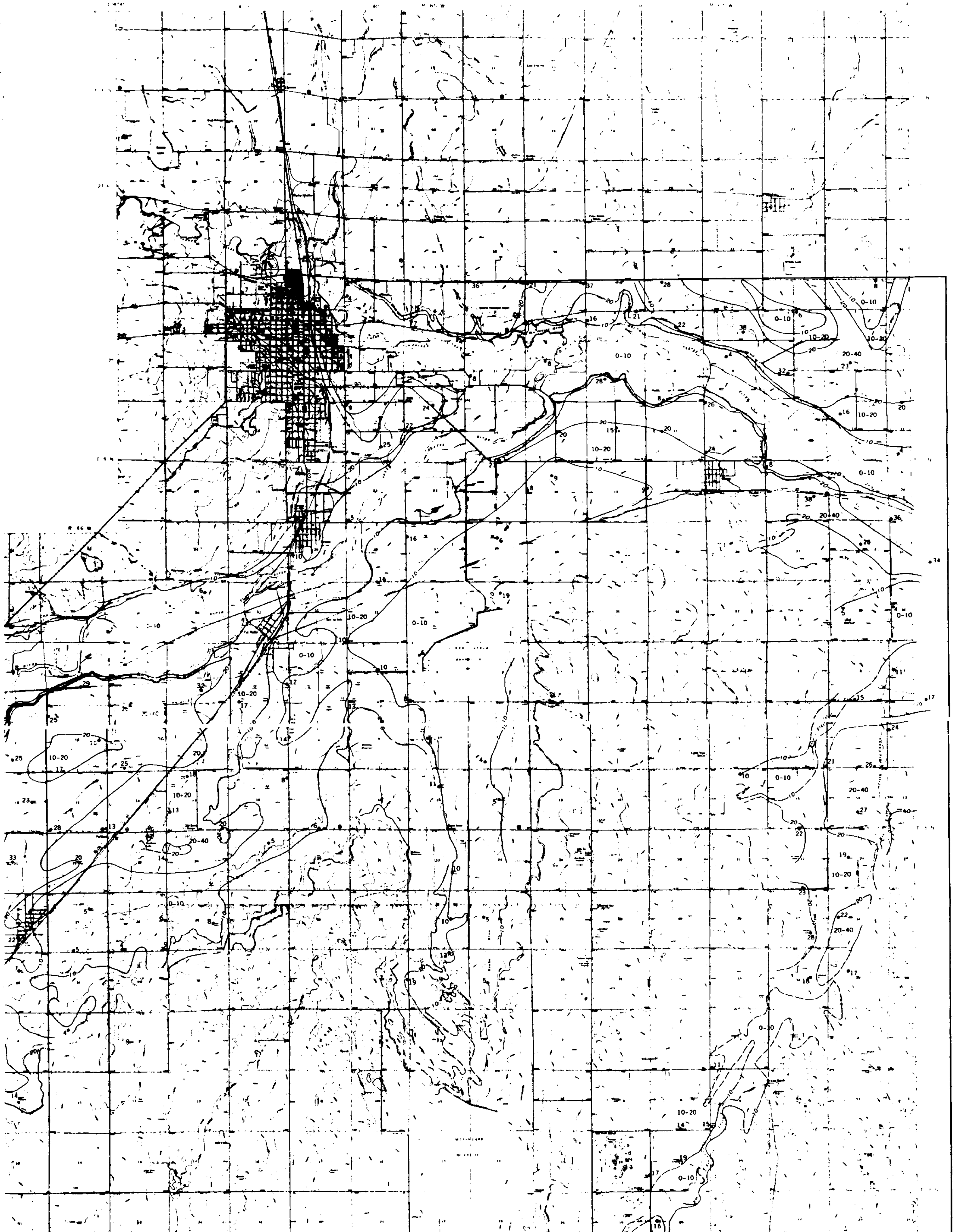

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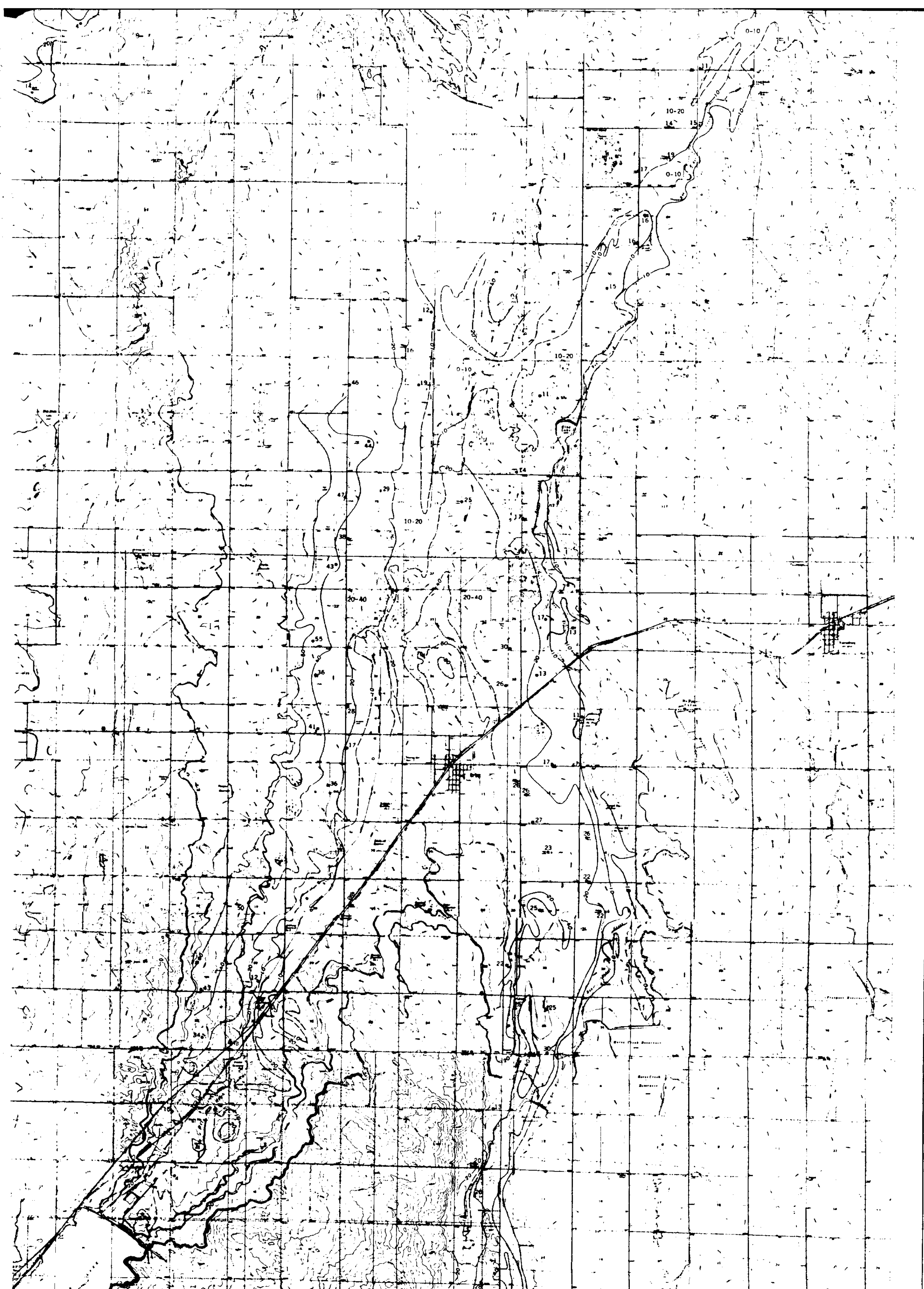

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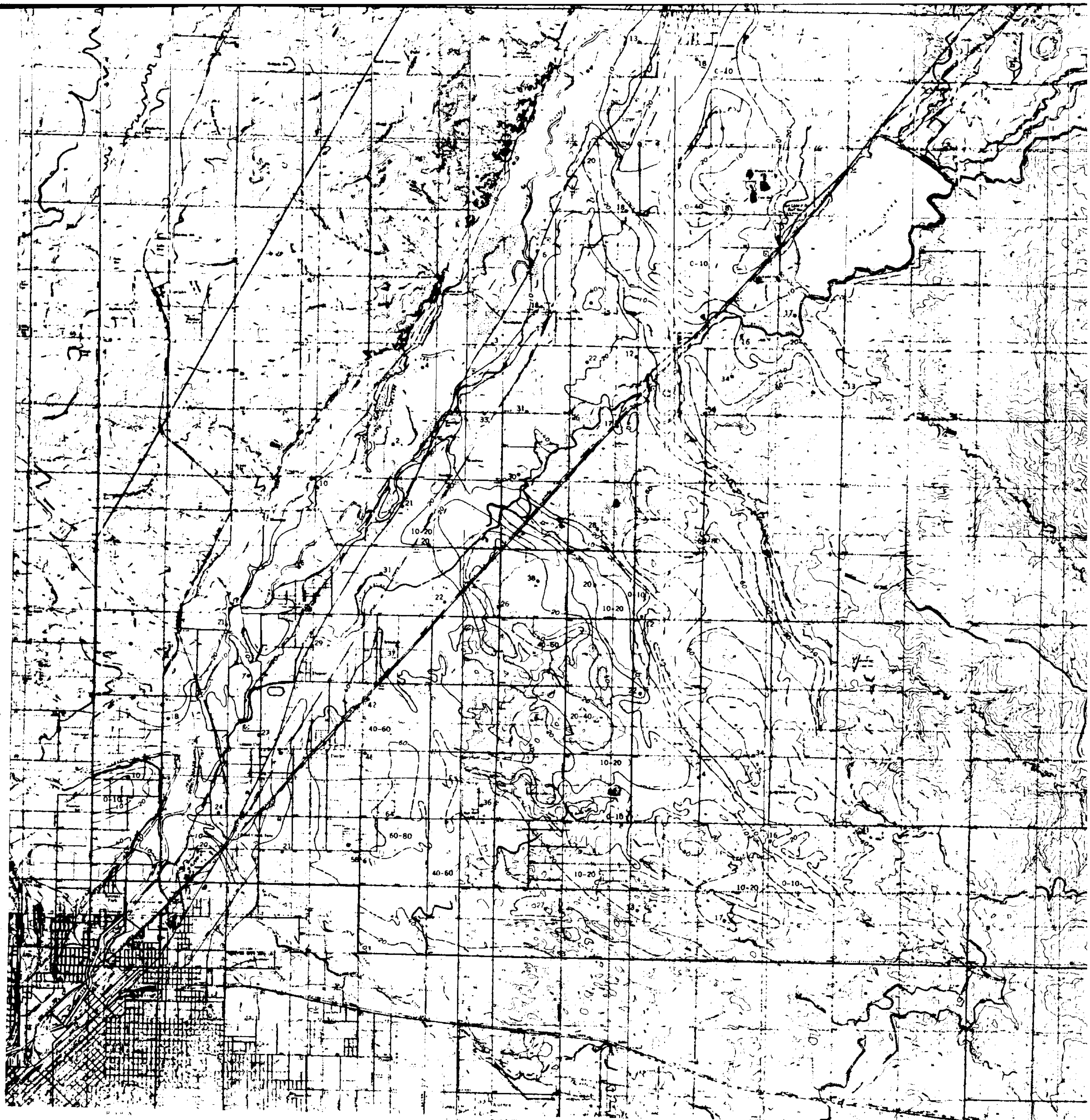

Base from U.S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTHWE
SHOWING THE DEPTH TO WATER IN NOVEMB

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

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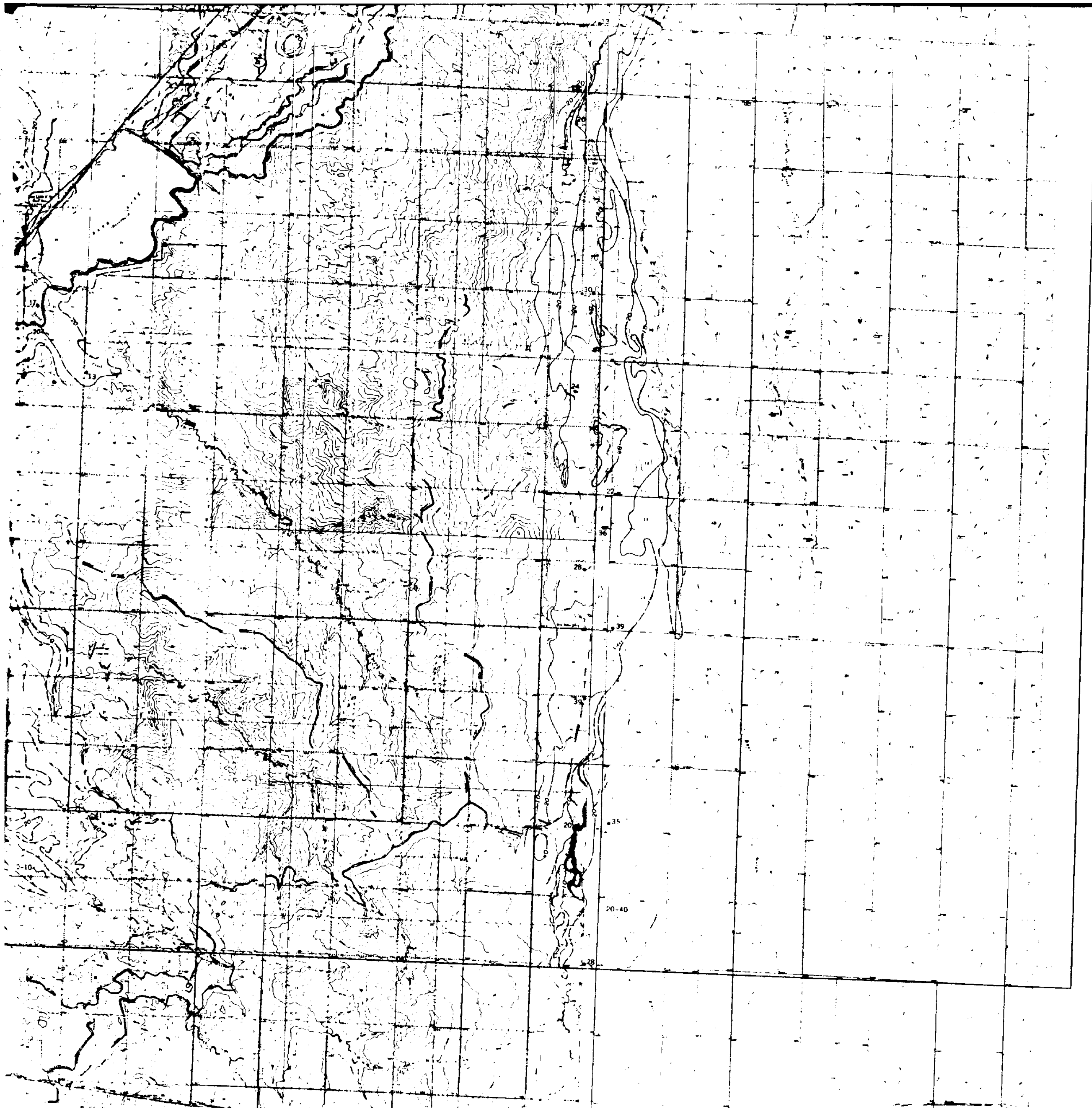


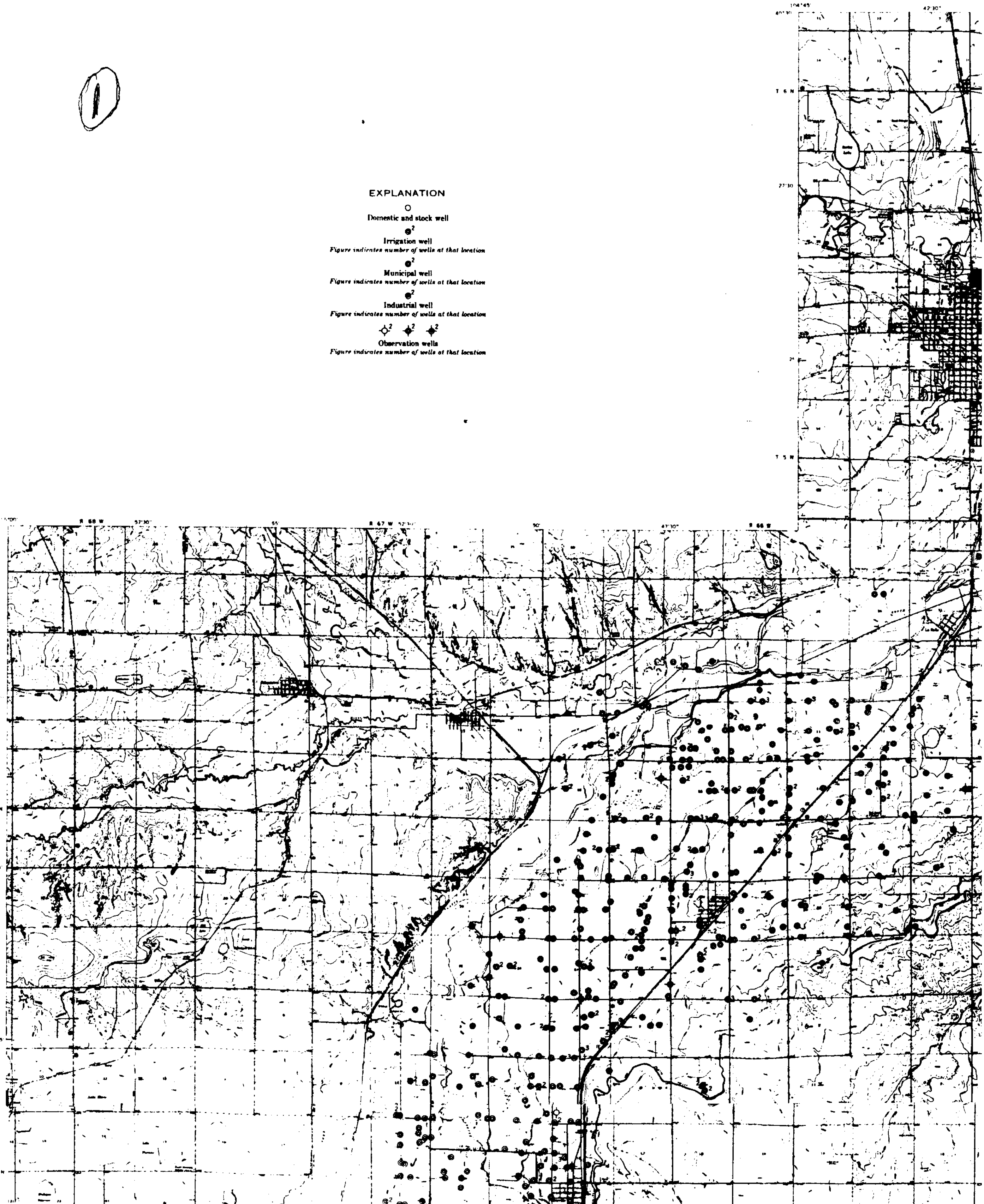
'ESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
IE DEPTH TO WATER IN NOVEMBER 1957

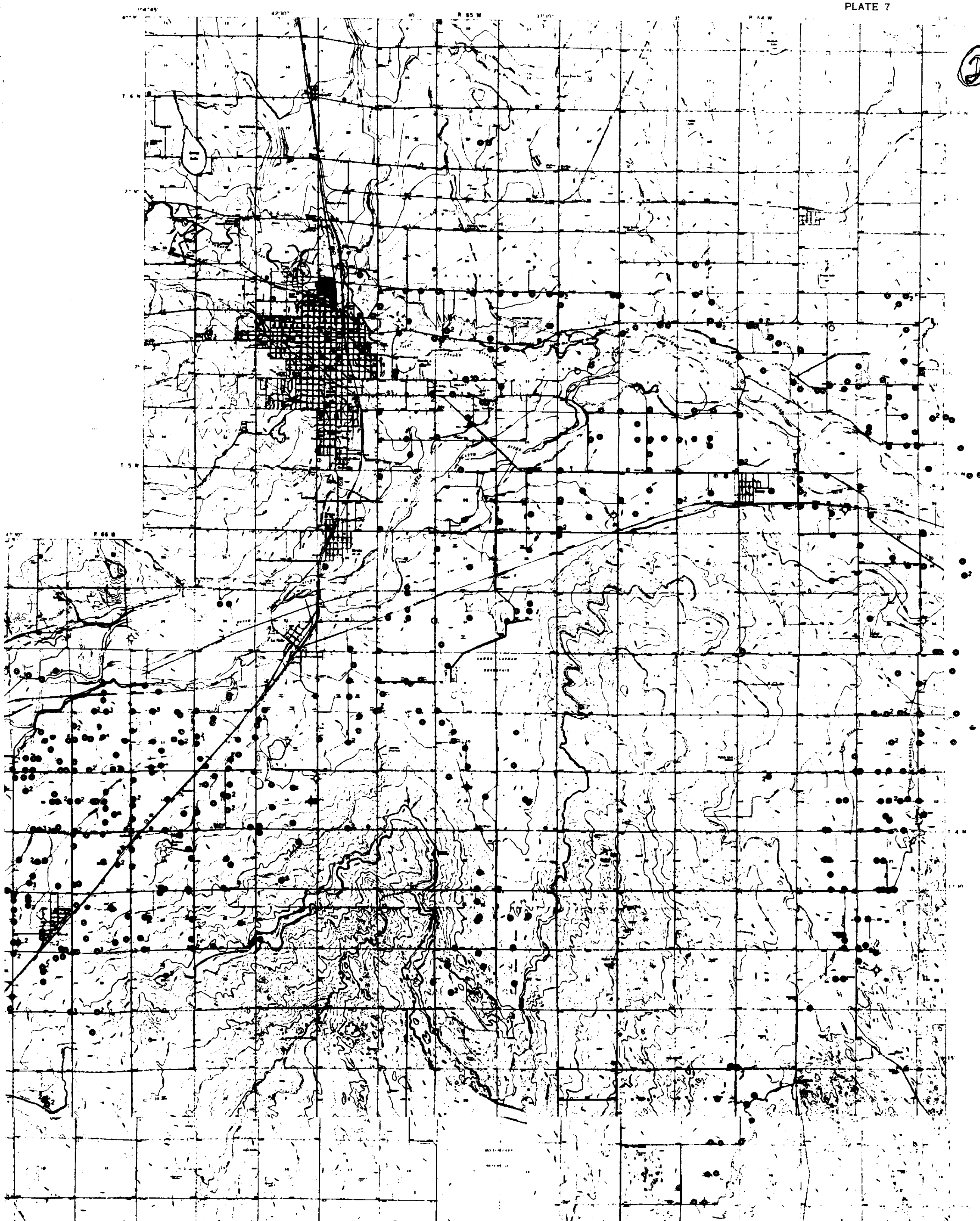
CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

84324 RC2

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

1





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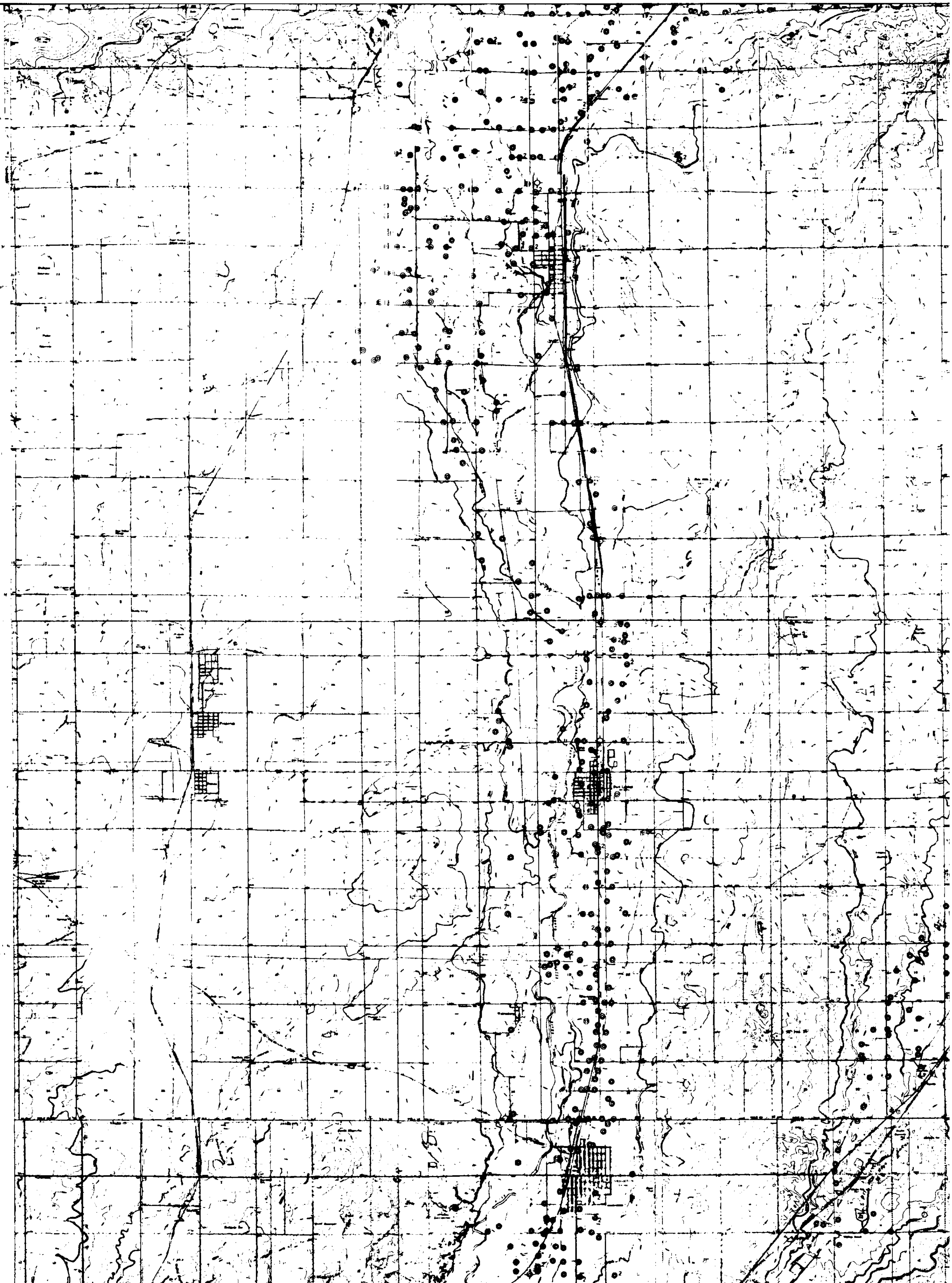

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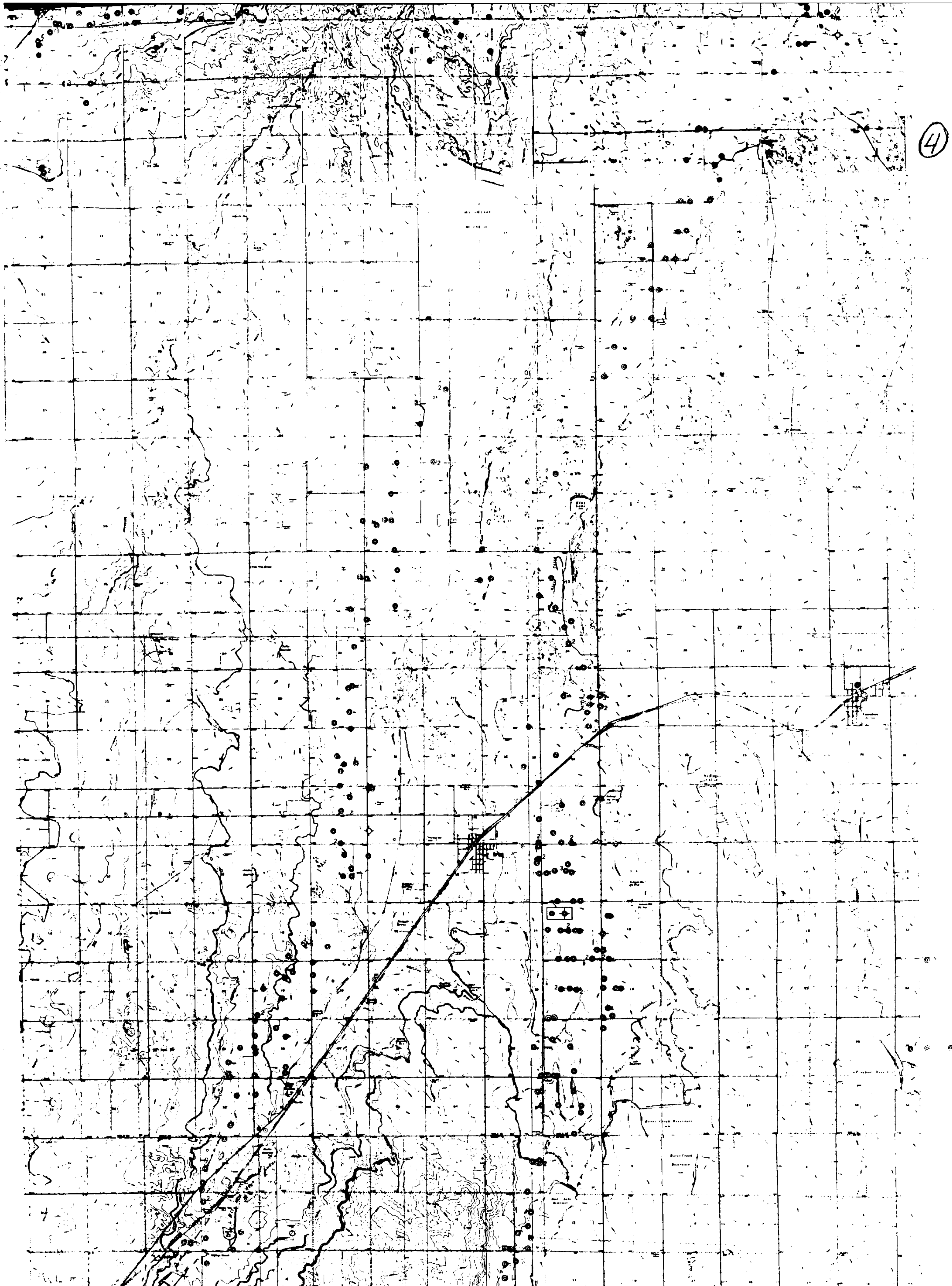

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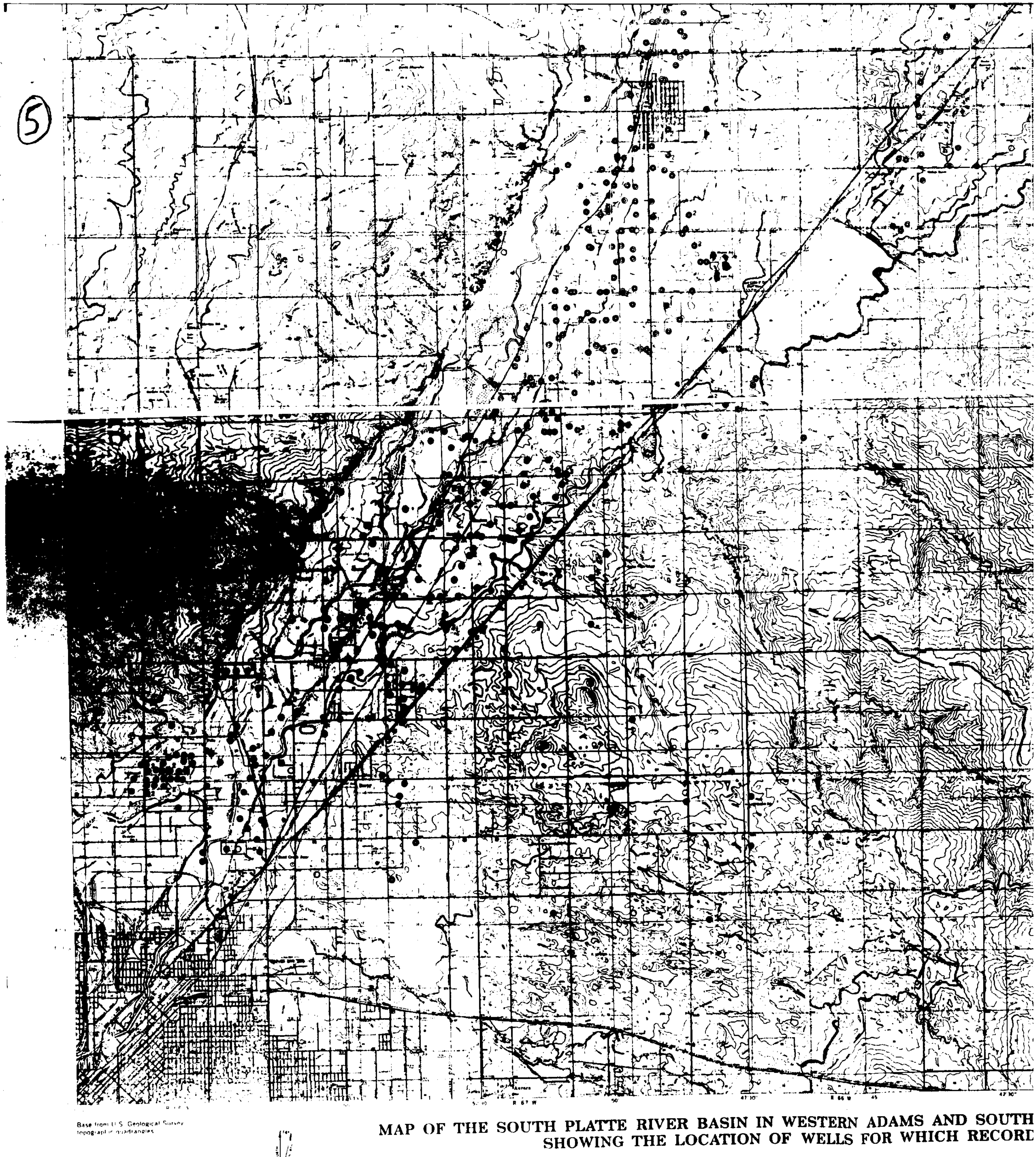
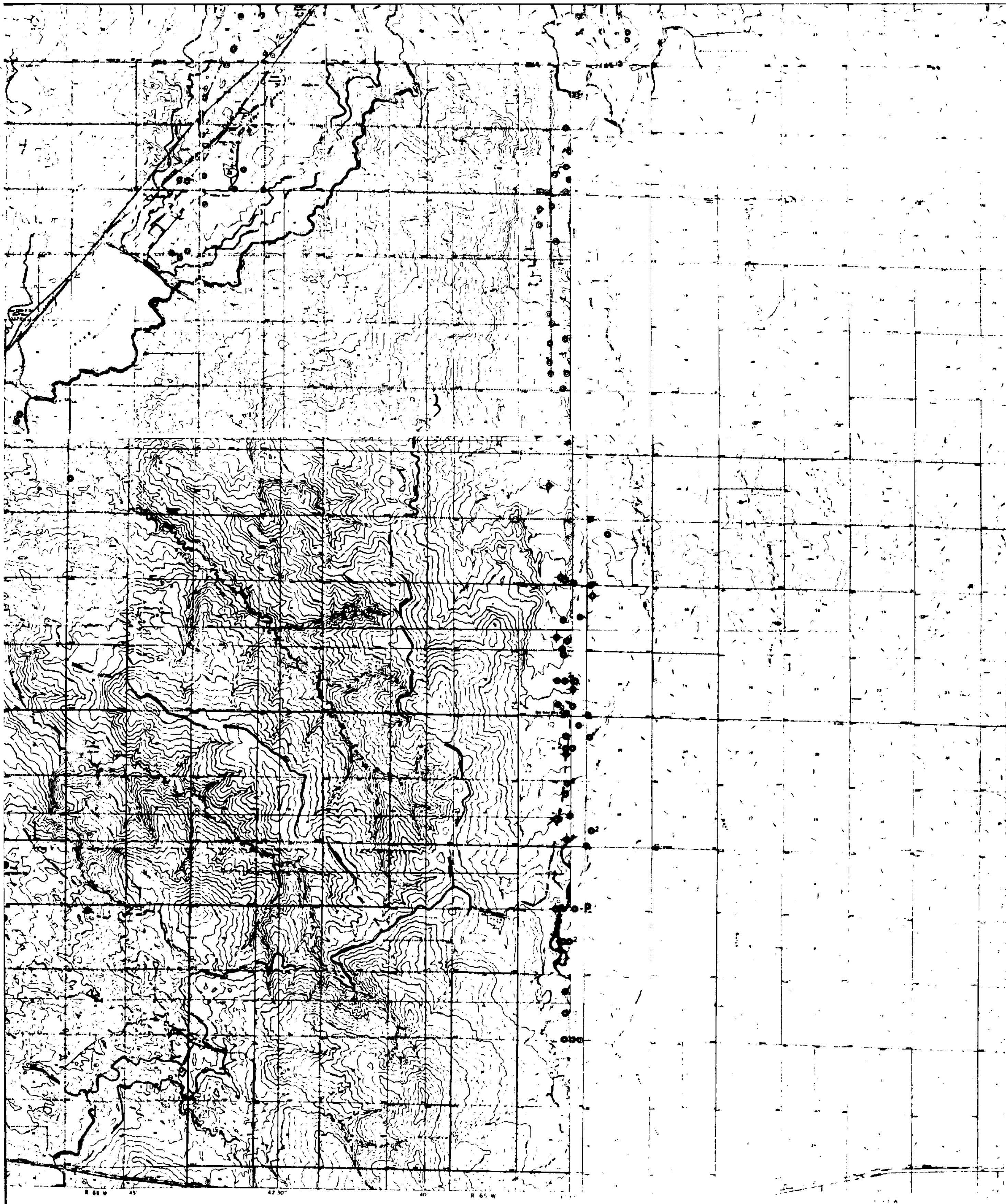


Base from U.S. Geological Survey topographic quadrangles

MAP OF THE SOUTH PLATTE RIVER BASIN IN WESTERN ADAMS AND SOUTH
SHOWING THE LOCATION OF WELLS FOR WHICH RECORD

6



N WESTERN ADAMS AND SOUTHWESTERN WELD COUNTIES, COLORADO
OF WELLS FOR WHICH RECORDS WERE COLLECTED

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

84324 R02